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PB-279 441

A Study of the Feasibility of Utilizing Solid Wastes for Building Materials
Phase II. Summary Report

Material Systems Corp, Escondido, Calif

Prepared for

Municipal Environmental Research Lab, Cincinnati, Ohio Solid and Hazardous Waste Research Div

Apr 78

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PB 279 441

EPA-600/2-78-092
April 1978

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A STUDY OF THE FEASIBILITY OF UTILIZING SOLID WASTES FOR BUILDING MATERIALS
Phase II Summary Report

by

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Contract No. 68-03-2056

Project Officer

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/2-78-092

2.

3. RECIPIENT'S ACCESSION NO.
PB279441

4. TITLE AND SUBTITLE
A STUDY OF THE FEASIBILITY OF UTILIZING SOLID WASTES FOR BUILDING MATERIALS: Phase II Summary Report

5. REPORT DATE
April 1978 (Issuing Date)

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
B.L. Duft, H. Levine, A. McLeod, and Y. Tsur

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Material Systems Corporation
751 Citracado Parkway
Escondido, California 92025

10. PROGRAM ELEMENT NO.
1DC618 SOS#5 Task 12 #1

11. CONTRACT/GRANT NO.
68-03-2056

12. SPONSORING AGENCY NAME AND ADDRESS
Municipal Environmental Research Laboratory--Cin., OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES
See also EXECUTIVE SUMMARY, EPA-600/8-77-006, PB-271 007/AS, and Phase I, EPA-600/2-78-091.

16. ABSTRACT

This document reports on a study to research and develop building materials containing organic and inorganic wastes and waste-derived products. Structural and aesthetic properties of variously formulated composites are evaluated. Limited economic analyses indicate that several commercially viable products could be derived from wastes.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Construction materials Fly ash Fire resistant materials Materials recovery Agricultural wastes	Solid waste Rice hulls Resource recovery	68C

18. DISTRIBUTION STATEMENT
RELEASE TO PUBLIC

19. SECURITY CLASS *(This Report)*
UNCLASSIFIED

20. SECURITY CLASS *(This page)*
UNCLASSIFIED

21. NO. OF PAGES
280

22. PRICE
A13-A01

EPA Form 2220-1 (9-73)

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ABSTRACT

This study researched and developed organic and inorganic materials and products from solid waste. Both the organic and inorganic waste systems provided superior products at a lower cost than comparable existing products. All of the proposed concepts are directly applicable to commercial construction needs and procedures. These products permit the translation of waste into cost-saving (and in some cases life-saving) useful materials. The next step required is to build and qualify these products under existing codes.

This report was submitted in fulfillment of Contract No. 68-03-2056 by Material Systems Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period July 1974 to September 1975, and work was completed as of September 1975.

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ACKNOWLEDGMENT

This is to acknowledge the assistance of the EPA Project Officer, Robert Landreth, and his associates, Albert Klee and Charles Rogers, of the Solid and Hazardous Waste Research Laboratory, National Environmental Research Center, Cincinnati, Ohio. They and their staff provided materials and support data useful in the preparation of this study. MSC staff personnel who also assisted in this study were S. Feher, L. Patag, B. Levenetz, J. Robinson, J. Stead, and H. Stanley.

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INTRODUCTION

Material Systems Corporation and the Solid and Hazardous Waste Research Laboratory of the National Environmental Research Center at Cincinnati, Ohio have initiated a joint effort development study for the application of waste materials for residential and commercial construction. This is a summary report of the Phase II activity. Phase I activity was reported in MSC Technical Report 74-12.(1). This report presented a comprehensive literature search. The data were reviewed and evaluated for potential matrix, reinforcement, and filler candidates. The more promising candidates were evaluated with limited laboratory studies. From these studies, two types of matrices, furfural derivatives and inorganic, were selected for further study. Seven reinforcement candidates and five fillers were selected for evaluation with the two matrices. Also, a modified work plan for Phase II was presented.

The Phase II activity demonstrated the potential technical and economic feasibility of utilizing waste materials for building construction. As the Phase II study progressed, it became apparent that there existed a multiplicity of product possibilities from waste materials. Therefore, it was jointly decided to concentrate Phase II activity on the development of the product and postpone specific qualifications until Phase III. The development included testing and evaluation to a sufficient level to assure qualification for specific products.

During the initial part of Phase II, it became apparent that reinforcement, filler, and matrix materials were closely related. Under certain conditions, the reinforcement and filler served the same purpose. Under other conditions, the effectiveness of the reinforcement was directly related to the matrix. This resulted in the following sequential steps to achieve the Phase II objective.

1. Reinforcing Systems - The selection of Phase I candidates were augmented by later discoveries. The cost, availability, and long-term supply of these materials were used to select those to be used in product development.

2. Filler Systems - With the exception of fly ash, most filler candidates became reinforcement candidates. Fly ash does have some product potential.

3. Organic Matrix Materials

   - Furfuryl alchohol and "in situ" furfural formation were the approaches utilized in developing an organic matrix material. The material is a product in itself and is evaluated as such.

4. Inorganic Matrix Materials - Various plasters and an MSC inorganic matrix were evaluated with various reinforcements. The resulting material products were foams, laminate and combinations.

5. Products-Organic Materials

- The organic materials were directly applied to specific products and evaluated for applicability, cost effectivenes and serviceability.

6. Products-Inorganic Materials

- The inorganic materials were applied to specific products and evaluated for applicability, cost effectiveness and serviceability.

Each of these are discussed in detail in the following report. Since waste economics, processability, and availability are pertinent to each study and are discussed therein, no separate presentation will be made.

REINFORCING SYSTEM

The reinforcing system in this study can serve a variety of purposes; in an organic matrix it can reinforce the resin and in many cases be the source of the resin, and/or also a combination of both. In an inorganic matrix it can reinforce the matrix, create voids in the matrix (syntactic foam) and/or a combination of both. The reinforcement systems investigated are presented in Table 1. A combination of agricultural waste, industrial waste, commercial waste and non-waste sources were considered. Feasibility of use as indicated in the table is defined as being able to produce a material either from organic or inorganic matrices. Acceptability is defined as being able to produce a material with properties that achieve commercial standards.

The first screening process consisted of determining the acceptability of products produced from the materials. This eliminated some materials from consideration as organic reinforcement and others from inorganic reinforcement. The second screening process was to determine the cost of the waste material F.O.B. source. Table 2 is a summary of these costs.

The transportation costs are a function of material density. The lighter the material, the higher the per pound cost. Therefore, it may be desirable to densify the lighter materials by compacting or baleing where practical. A 500 mile transportation radius was selected as this would provide a factory with 785,400 square miles of producing waste sources which should be more than adequate to supply its needs. Table 3 presents typical transportation costs.

The third screening was to rate the reinforcement on product potential. Table 4 presents the ratings for reinforcements used with organic matrices. Table 5 presents the ratings for reinforcements used with inorganic matrices. A value of 20 was established as the preferred level for selection. However, a level of 16 could be considered the acceptable level for selection. The ratings were based on eight criteria listed on each table and were rated 0 to 4. The rating of 2 for a criteria represents reasonable potential. Therefore, a total of 16 represents an average reasonable potential. Nail retention is used as a criteria for applicability to conventional construction. The other criteria represents requirements for a feasible product.

From this review for an organic matrix, rice hulls, peanut shells, corn cobs, wood shavings and Silvacon, are the best candidates. Cotton waste would be considered if the disposal problems are sufficient to counter the other poor characteristics discussed in the matrix section. Straw has a surface material which must be either broken up or destroyed before it can be used. Waste paper cannot generate furfural and therefore by itself is not effective. When used in combination with other materials, it still showed poor promise.

For an inorganic matrix, rice hulls are the best waste reinforcement. Plastic scrap and reject styrofoam beads show definite potential. However, the limitation on supply (Table 6) is at this time a limiting criteria. One source would be from municipal solid waste. This would require some form of sorting. This development would be considered too far in the future to be considered here. Fly ash, sisal scrap, and Silvacon are of lesser interest. All other candidates should be disregarded.

In developing a specific product, some of the less promising materials offer a specific function which requires that they not be completely eliminated. This will be discussed in the product section.

The last screening step was source and availability determination. These are summarized for the more promising materials in Table 6.

Table 1
Summary of Reinforcements

Reinforcement	Used with Organic Matrix		Used with Inorganic Matrix	
	Feasible	Acceptable	Feasible	Acceptable
Agricultural Waste				
corn cobs	X	X		
straw	X	X	X	
rice hulls	X	X	X	X
cotton waste	X	X	X	X
peanut shells	X	X		
Industrial Waste				
wood bark	X	X	X	X
saw dust	X	X		
pine shavings	X	X		
Alder shavings	X	X		
Douglas Fir Shavings	X	X		
Redwood shavings	X	X		
Ash shavings	X	X		
plastic scrap			X	X
reject styrofoam beads			X	X
reject graphite fibers			X	X
Sisal scrap			X	X
fly ash			X	X
Commercial Waste				
waste paper	X	X		
paper pulp			X	X
computer cards			X	X
Non-Waste				
glass fibers			X	X
Silvacon 412	X	X	X	

Table 2
Typical Costs of Reinforcements FOB Source

Reinforcement	$Cost/lb.
Corn cobs	0.0075*
Straw	0.0020-.010**
Rice hulls	0.0020-.0025
Cotton Waste	0.0020-.010
Peanut Shells	0.0075***
Wood bark	0.01****
Saw dust	0.01****
Pine shavings	0.01****
Alder shavings	0.01****
Douglas Fir shavings	0.01****
Redwood shavings	0.01****
Ash shavings	0.01****
Plastic scrap	Unable to establish a cost
Reject styrofoam beads	0.25
Glass fibers	0.43
Silvacon 412	0.0465

* Cornnuts, Inc. - Oakland, California

** The cost would vary with demand. It will not be less than rice hulls or more than wood shavings.

*** Gold Kist Feed Mill Company

**** This is a nominal cost paid by chipboard manufacturer. The cost may vary 10% with supply and demand.

Table 3
Reinforcement Transportation Costs for 500 Miles

Reinforcement	$ Cost/lb.
Corn Cobs	0.0062-0.0125
Rice Hulls	0.014
Peanut Shells	0.013
Wood Shavings	0.010

Table 4
Rating of Reinforcements used with Organic Matrice

Criteria
Availability
Pentosan Content
Nail Retention
Dimensional Stability
Ease of Processing
Density
Flammability
Total Materials Cost

Rating
0 - Unacceptable
1 - Poor Prospects
2 - Reasonable Potential
3 - Acceptable, More Work
4 - Acceptable, All Respects

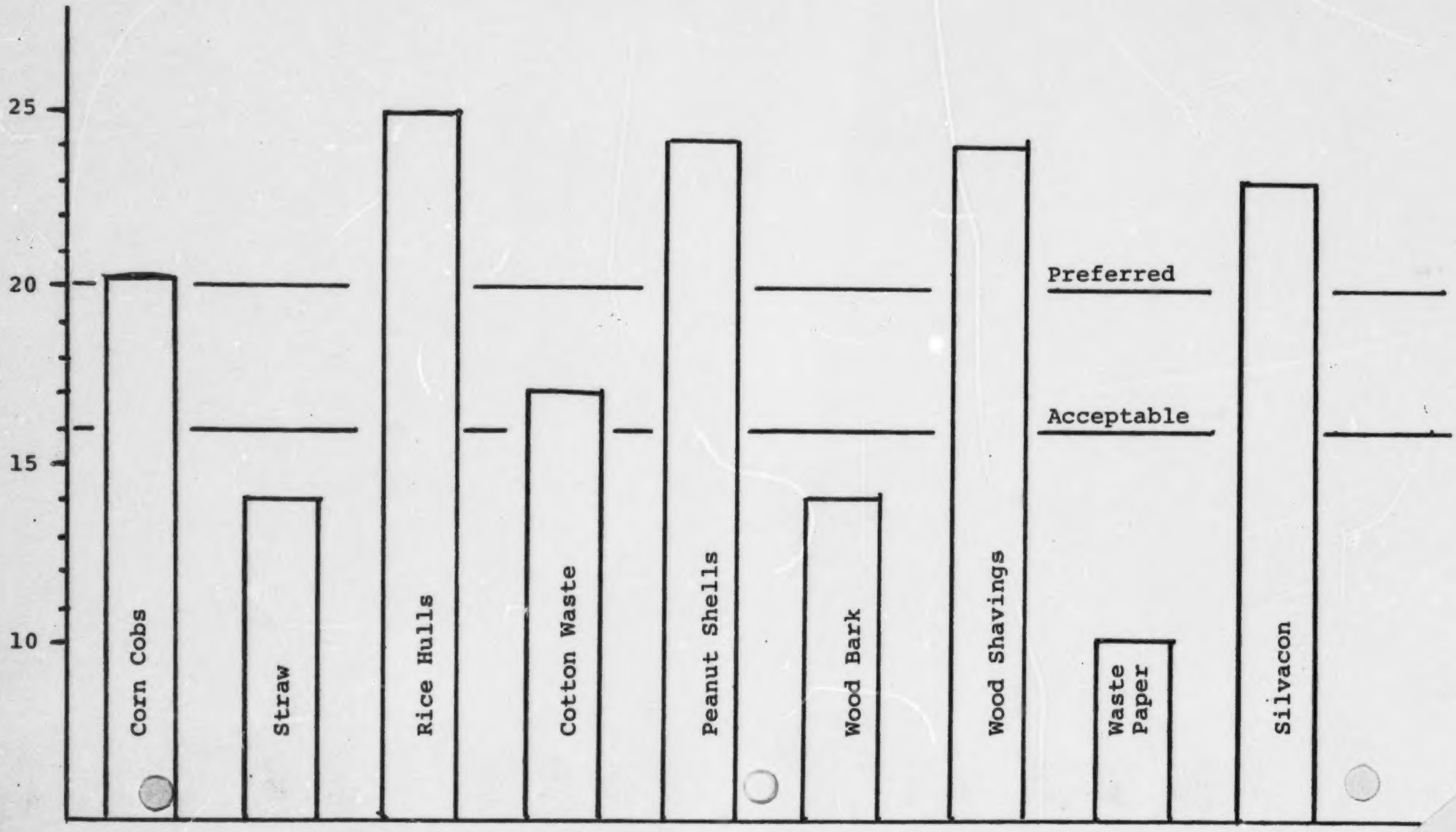
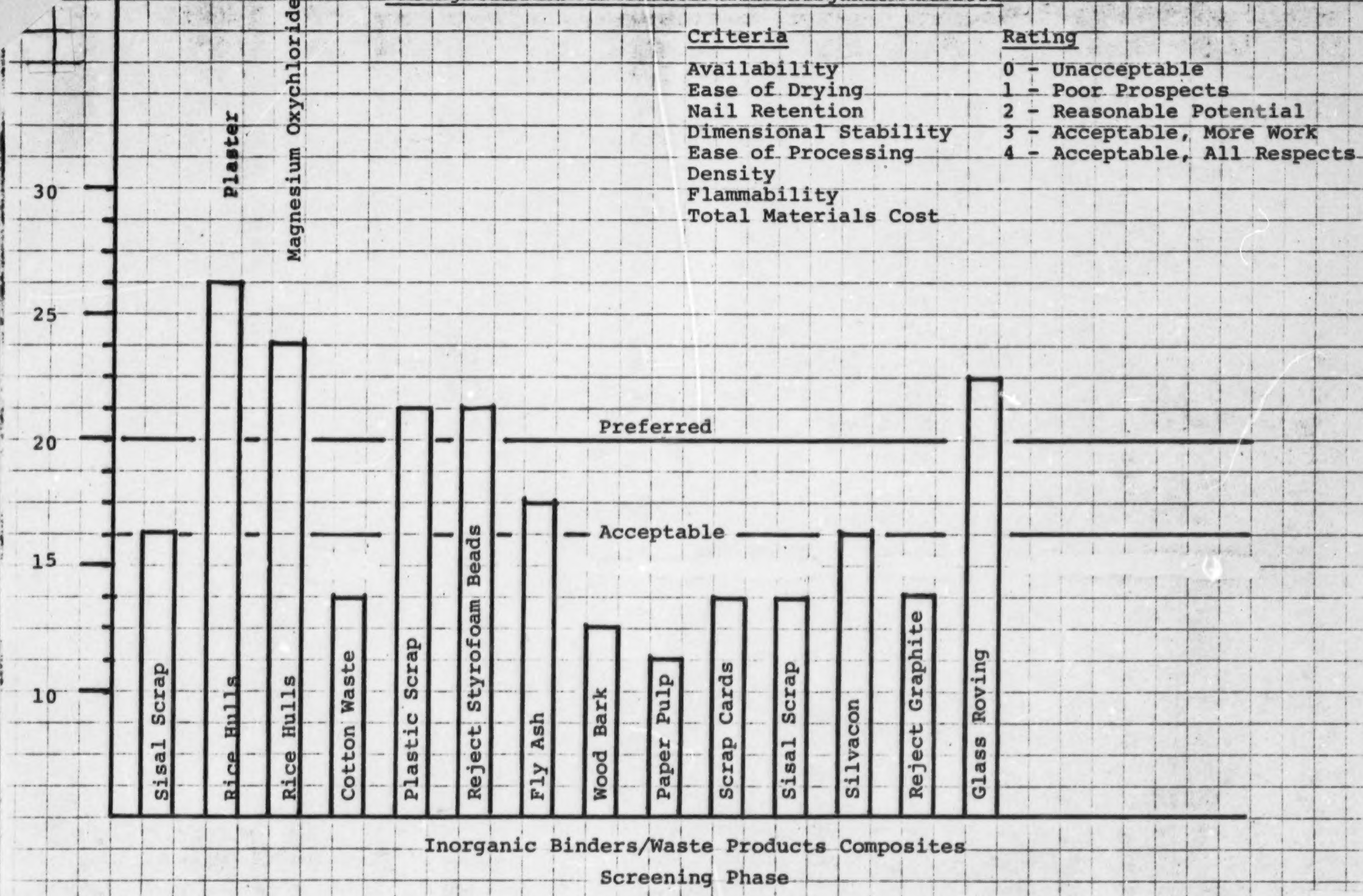


Table 5

Ratings of Reinforcements with Inorganic Matrices



Criteria	Rating
Availability	0 - Unacceptable
Ease of Drying	1 - Poor Prospects
Nail Retention	2 - Reasonable Potential
Dimensional Stability	3 - Acceptable, More Work
Ease of Processing	4 - Acceptable, All Respects
Density	
Flammability	
Total Materials Cost	

Table 6
Source and Availability of Reinforcement

Reinforcement	Quantity	Source
Corn Cobs	1,500-2,000 tons/yr	Cornnuts Inc., Oakland, Ca.
Corn Cobs	Similar	Seed milk in California and Midwest
Rice Hulls	3,000 tons/month	Comet Rice Mills, Houston, Texa
Rice Hulls	+150 tons/month	C. E. Grosjean Rice Milling Co., San Francisco, Ca.
Rice Hulls	25,000-30,000 tons/yr	Shifflet Bros., Gridley, Ca.
Rice Hulls	Similar	Louisiana and Texas
Cotton Waste	Unknown	Unknown
Peanut Shells	350,000 tons/yr	Texas, Louisiana, Georgia, Alabama, Arkansas, Mississippi, Florida
Peanut Shells	3,000 tons/month	Gold Kist Seed Mill, Comanche, Texas
Wood Shavings	Unlimited	Northwest, South and Southeast
Silvacon	Unlimited	Weyerhauser
Plastic Scrap	Limited	Unknown
Reject Styrofoam Beads	Limited	Unknown
Fly Ash	30×10^6 tons/yr	Coal-fired furnaces

FILLER SYSTEMS

The purpose of a filler is to improve properties or to reduce the utilization of more expensive material. Fly ash was the primary candidate considered because of its universal availability. The first application was to consider fly ash as a filler for polyester fiberglass reinforced composites. Samples were made on the MSC continuous laminate production process. Calcium Carbonate is the presently used filler. Fly ash filled specimens exhibited equivalent mechanical and physical properties and exhibited an excellent retention of appearance after 1500 hours of continuous exposure in an accelerated weathering test.

Since transportation is the significant element of cost in both, only the amount of utilization can be used for cost effective evaluation. Fly ash unfortunately exhibits a thixotropic behavior in polyester resin. This limits the concentration of material useable. Tests demonstrated that a maximum level of 75 parts per hundred of resin can be used. This compares to 100 parts of calcium carbonate per 100 parts per resin that is feasible. Thus, for a given amount of resin-filler mix, the fly ash would require more resin and therefore, be a less effective filler for inorganic waste composites. It was determined that fly ash can be used as a one to one replacement for calcium carbonate or casting plaster when used as a filler with the MSC inorganic matrix. There is a color problem if the material is to be exposed because the fly ash products range from dark grey to almost black.

Fly ash can definitely be used as a filler with conventional polyester reinforced glass composites or with MSC inorganic matrix composites. Properties are equivalent. There are no cost advantages as the material being replaced is approximately the same cost as the fly ash. The primary advantage is that this is a cost effective disposal of fly ash.

Some of the other materials evaluated as fillers were sawdust, paper pulp, waste paper, and computer cards. These materials were generally ineffective in conventional organic systems, the waste organic system, or the inorganic system.

ORGANIC MATRIX MATERIALS

Furfural-type matrices were selected as the most promising organic system. This selection was based on the results of the Phase I study. To evaluate furfural systems, the following approaches were taken.

1. Conduct processing and manufacturing studies with a commercial furfuryl alcohol-based resin.

2. Three-step process of "in situ" formation of furfural from waste, with additives.

3. Two-step process of "in situ" formation of furfural from waste without added organic resins or resin precursors.

Each of these are discussed in detail in the following text.

Processing and Manufacturing with Commercial Furfuryl Alcohol

A commercial resin, based on furfuryl alcohol and furfural, was used initially to determine the feasibility of the concept. The resulting matrix material would be very similar to one obtained from resin generated "in situ". A serious failure with a commercial available resin would indicate a poor prognosis and be the basis for discarding the concept with a minimum loss of time and money.

Standard press molding techniques were evaluated in Phase I(1) with Quaker Oats Quacor furfuryl alcohol based resin. It was determined that large amounts of vapors were generated during the cure. The adaptability of the system to a continuous production process was also determined. Two experimental runs were conducted on the MSC continuous processing machinery using Quaker Oats furfuryl alcohol-based resin reinforced with glass fiber. The formulations for Run I are presented in Table 7. The resin mix was twice as viscous as that of the production polyester mix. The line speed was 3 feet per minute. Production speed varied between 5 and 10 feet per minute. Only three ovens were used. Oven #1 was set at 170 degrees Farenheit, Oven #2 was set at 180 degrees Farneheit, and Oven #3 was set at 210 degrees Farenheit. All of the panels were gelled coming out of Oven #1. None of them were fully cured at the end of Oven #3. The panels were air cured overnight and postcured for 10 minutes at 260 degrees Farenheit plus 10 minutes at 285 degrees Farenheit the next day. Formulation "C" never cured because of the plaster causing a change in pH and was discarded from further evaluation. Formulation "A" and "B" were evaluated for smoke density using the American Instrument Co. Smoke Density Chamber (National Bureau of Standards Technique) and for flame spread using a modified ASTM-E-84-70 test. Mechanical properties were also run. The results are compared in Table 8 with commercially available production building material. Run II was conducted to evaluate variations in filler and catalyst. The formulation are presented in Table 9. The line speed again was 3 feet per minute. Oven #1 was set at 160 degrees Farenheit, Oven #2 was set at 215 degrees Farenheit, and Oven #3 was set at 350 degrees Farenheit. All specimens appeared well cured after Oven #3. However, some of the specimens were postcured at 350 degrees Farenheit for 2 hours. Mechanical and flame spread tests were run. The results are presented in Table 10 and compared with polyester production parts.

Table 7
Formulations for Run I

	A	B	C
Resin	Quacor RP100A - 2000g	Quacor RX300 - 2000g	Quacor RP100A - 2000g
Solvent	Furfuryl Alcohol-100g	Furfuryl Alcohol-100g	Furfuryl Alcohol-100g
Catalyst	Quacor RP104B - 60g	Quacor RP104B - 60g	Quacor RP104B - 60g
Filler	Huber 35 (1) - 1200g	Huber 35 (1) - 1200g	Casting Plaster-1800g
Other	(75% TiO_2) (25% furfuryl - Alcohol) 25g	(75% TiO_2) (25% furfuryl - Alcohol) 25g	(75% TiO_2) (25% furfuryl - Alcohol) 25g

(1) Huber 35 is a fine clay with acidic pH.

Table 8
Evaluation of Run I - Formulations A and B

	Density	Smoke	Flame Spread	% Glass Fiber	Tensile
A	.052 lb/m^3	5	25	29	5240 psi
	.069 lb/m^3	0	17	28	5544 psi
Commercial Building Materials		400	100		2000-5000 psi

Table 9
Formulations for Run II
(Parts per hundred of Resin)

Form.	Resin	Solvent	Filler	Catalyst
D	Quacor RP100A (100)	Furfuryl Alcohol (5)	Huber 35 (60)	RP104B (3)
E	" " (100)	" " (5)	" " (80)	" (3)
F	" " (100)	" " (5)	" " (100)	" (3)
G	Quacor RX300 (100)	" " (5)	" " (60)	" (3)
H	Quacor RP100A	" " (5)	C-31 (1) (60)	" (3)
I	" " (100)	" " (5)	" " (60)	" (4)
J	" " (100)	" " (5)	Huber 35 (60)	" (4)
K	" " (100)	" " (5)	" " (60)	" (3)

(1) C-31 is Alumina Hydrate

Table 10
Evaluation of Run II - Formulation D - K

	Flame Spread		Tensile	
	As Cured	Post Cured	As Cured	Post Cured
D	37	16	6850	8015
E	20	12	5480	6020
F	20	25	3680	4050
G	16	18	7380	6310
H	31	18	5080	4890
I	33	18	4175	4780
J	33	27	3490	3560
K	22	18	7630	7600
Commercial Building Materials	100		2000-5000	

Formulation A and D are nearly identical. The portions of constituents in A, B, D and K are equivalent. Therefore, these appear to be the correct formulation base from which to develop the furfural system. It may also be concluded that the furfural is processable on the production system and will develop a product equivalent to or superior to the present qualified product. These studies indicated no insurmountable difficulty in processing composites based on matrix resins containing the furone ring system.

If these materials are to be considered for use as exterior wall panels, then an aesthetic surface will be required. One approach would be to embed or adhere crushed rock or crushed glass, plastic, or other qualifiable waste to the surface. A study was made to determine the approach most suitable. Two approaches were evaluated.

a. Composite was deposited on a conveyor, the crushed surface material applied, and the entire system cured.

b. Composite was deposited and cured. Then an adhesive was sprayed on the surface, the crushed surface material applied, and the surface cured.

Figure 1 is a cross-section of the composite utilizing system (a).
Figure 2 is a cross-section of the composite utilizing system (b).

As can be seen from these cross sections, the crushed material is more secrued by system (a) than (b). Samples from both methods were placed in a Weatherometer for a 2000 hours evaluation. Four short runs were made on the MSC lamination machinery to evaluate these two techniques.

The results after 2000 hours showed that the rocks by system (a) were still secure and could withstand abrasive action. The rocks by system (b) had already dropped off and those that remained could be scraped off by use of a finger nail.

Three-Step Process of "In Situ" Formation with Additives

Furfural can be obtained from such materials as rice hulls and corn cobs by acid hydrolysis usually at high temperatures and pressures. The purpose of this study was to

1. Determine if hydrolysis can take place without pressure, and

2. Since reaction at lower pressures mean lowered reaction temperature, will the yield of furfural be reduced to an inadequate level?

Additives are used to interact with the furfural, and/or to "prime the pump" for furfural formation, and/or to reinforce and absorb excess furfural.

There are several ways to carry out the reaction between rice hulls (source of furfural) and wood bark (source of phenolic material) in the presence of acid to produce, "in situ", a novolak resin. The program first evaluated the simplest, most direct route - namely, attempting hydrolysis and ring closure of rice-hull pentosans in the presence of the wood bark without use of pressure equipment. It was our belief

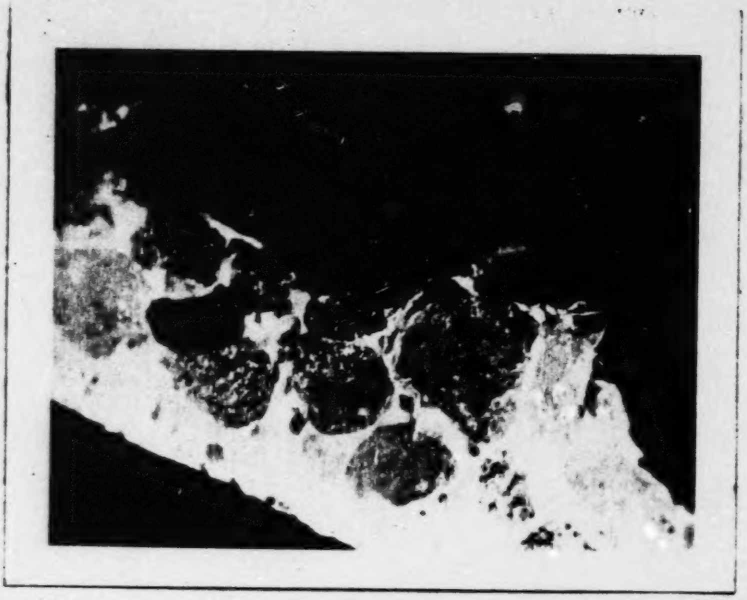


Figure 1: Composites Utilizing System (a)

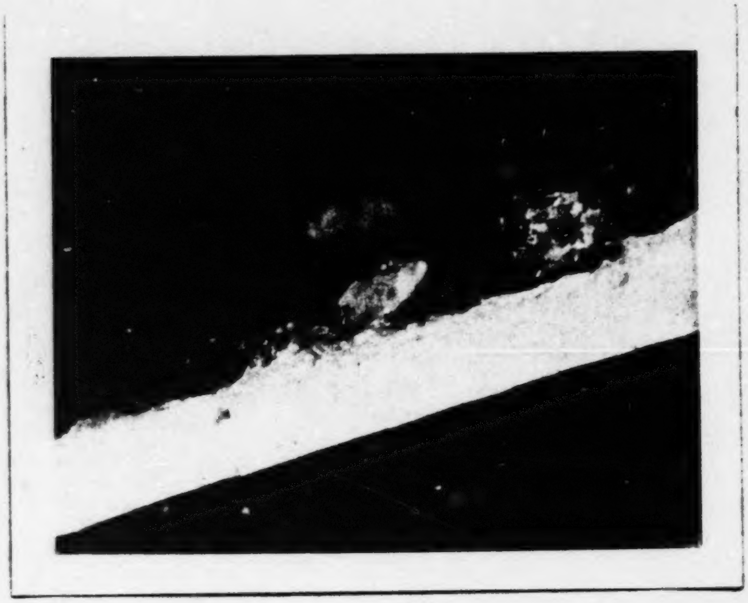


Figure 2: Composites Utilizing System (b)

that a reasonable possibility exists for the furfural produce "in situ" would react rapidly with the phenolic material. This novolak would then be cross-linked by use of hexamethylene tetramine or furfural.

Hydrolysis of rice hulls was attempted by refluxing with dilute hydrochloric acid after which phenol was added and the mixture refluxed further. The resulting mix was air dried (50 degreec Centigrade). To the dried material was added hexamethylene tetramine (hexa) and the mixture molded at 150°C, and 250 psi pressure. There was no flow and the molding was resin starved and easily breakable. A second series of experiments was carried out, hydrolyzing rice hulls, (in dilute HCl), in the presence of phenol.

The first molding trials were carried out on the hydrolysis mixture after addition of Silvacon 412 as filler. This was added in order to absorb the excess liquid that was available. Ten percent dry weight of chopped glass fibers (1.4" long) were added as reinforcement. These moldings showed high flow; the resulting product strongly adhered to the metal mold and could not be removed as one piece. These experiments indicated that rice-hulls hydrolysis yielded materials which were condensable with phenol and the resulting polymer exhibited excellent adhesion.

Improved integrity of the moldings was achieved by adding to the mixtures (previously mentioned) about 7-10% hexa. Flow and strength properties improved significantly although there were voids in the surface (see Figure 3); however, the rice hulls and glass fibers were evenly wetted with resin.

The exact amount of furfural produced in a process with no pressure, and under normal reflux conditions (@ 100°C) was not determined; however, it was found, that an acid concentration of 3-6%, and a reflux time of 15-20 hours gave enough furfural to produce a moldable material. Reflux times of about 3-5 hours, and acid concentrations of about 1% were attempted, but there was no resin flow during the molding process, and the moldings fell apart upon removal from mold.

Hydrolysis of rice hulls or corn cobs, without wood bark or other phenolic containing materials, was carried out under the above mentioned favorable conditions (Table 11). In each case, Silvacon 412 was added after hydrolysis to absorb excess of furfural which was not absorbed by the rice hulls or corn cobs; the Silvacon 412 also acted as a filler. The mixtures were partially dried at 50°C, (a small amount of moisture is required to get proper flow) and consequently molded for 20 minutes at 150°C, 500 psi, pressure.

These mixtures were moldable without the presence of phenolic substance, and yielded products with possible structural properties. The addition of shredded newspaper was thought to improve the strength. Moldings were also made with some additional furfural. The process that was actually taking place may be a self-polymerization of the furfural, because the ph of the mixtures before molding was about 2.

Further work was carried out on acid hydrolysis of rice hulls or corn cobs in the presence of western Hemlock bark in three different weight proportions, namely rice hulls or corn cobs, with/wood bark = 2:1, 2:1:5, 1:1 (see Table 11).

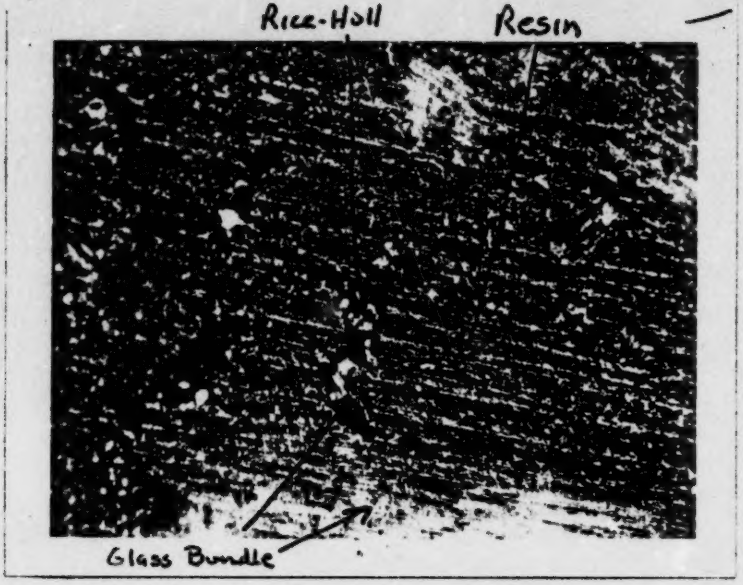

Rice-Hull
Resin
Glass Bundle

Figure 3

Organic Molding with Rice Hulls

Silvacon 412 was added to all these mixtures in a proper amount, to fulfill the functions mentioned earlier. The effect of added furfural or furfuryl alcohol was tried with these mixtures to improve flow and final properties (See Table 12). Shredded newspaper was the only reinforcement used because it was the most compatible as compared to others, e.g. fiberglass, cotton rags, or cheese cloth.

All the above mentioned mixtures yielded cross-linked resins which were insoluble in water, and apparently may not have lost much of their strength after water immersion; a first indication of this was hardness measurements on wet sample after 24 hours immersion (see Tables 13 and 14).

Some experiments were carried out which yielded non-crosslinked, watersoluble resins. The first series of such experiments were carried out on acid hydrolyzed, and acid catalyzed mixtures including rice hulls or corn cobs with wood bark. To these were added various amount of hexamethylene tetramine with or without the presence of an alkaline promoter, e.g. calcium oxide or paraformaldehyde in the presence of bases, e.g. solium hydroxide, calcium oxide or ethylene diamine.

Another series of experiments was carried out on mixtures hydrolyzed with acid in the presence of wood bark and then making pH of mixture basic followed by further reflux. This process was initially believed to have two advantages. The extracted phenolic compounds would react more readily with furfural and the resin obtained would be a two-stage resin, which can be cross-linked with added hexamethylene tetramine, parafolmaldehyde or furfural. Unfortunately, all these mixtures yielded water-soluble resins. Attempts to eliminate this by postcure, or molding at 200°C also failed.

The solubility of the western hemlock bark constituents under basic condition might be the cause of this phenomena because some of these extractables do not condense and remain soluble even after the molding process. From the results summarized in Tables 13 and 14, the following can be noted:

1. The densities of moldings range from 0.9 to 1.40 b/cc. These variations were due to the void content (observed microscopically) and precision of the density determination.
2. Water pick-up after one hour immersion ranges between 7-50%. For most of the samples the additional water absorbtion after 24 hours is little, for some, up to 100%.
3. The hardness measured on wet samples after 24 hours immersion remained essentially constant. This leads to the conclusion that the water was primarily filling void space, and not absorbed into the material.

A quantitative determination of furfural formed by acid hydrolysis was conducted. The acid hydrolysis method used on rice hulls and corn cobs to produce furfural is much less vigorous than the industrial method involving high temperatures and pressures. It was thus anticipated

Table 11
Composition of Hydrolysis/Condensation Mixtures

Mixture No.	Corn Cobs (g)	Rice Hulls (g)	Wood Bark (g)	Con. HCl (ml)	Water (ml)	Silvacon* 412 (g)
30	120	-	-	12	200	50
26	120	-	60	12	200	70
23	120	-	90	12	200	70
25	120	-	120	12	220	60
29		30	-	3	115	40
28		30	15	3	115	30
24		30	22.5	3	115	30
27		30	30	3	115	30

* Added after completion of hydrolysis.

Note: The total of hydrolysis mixture and Silvacon is designated as "wet mixture".

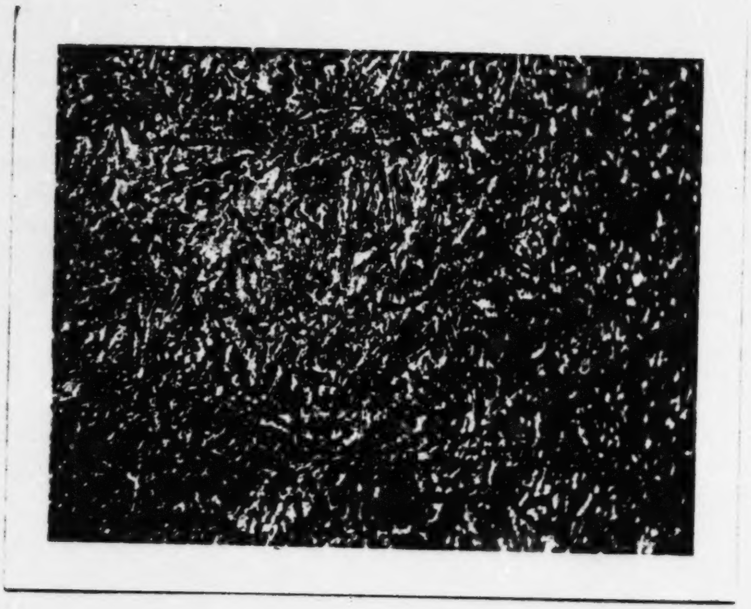


Figure 4: Photomicrograph of sample 30A and Silvacon (needle-like material) (X15)

Table 12
Formulation of Molding Mixtures

Sample	Wet Mixture (g)	Furfural (ml)	Furfuryl Alcohol (ml)	Newspaper (g)
A	35			
B	35			3
C	35	1		2

Above - for mixtures: 29, 30

A	24			
B	24			2
C	24	1		2
D	24		1	2
E	24		2	2

For mixtures: 23, 24, 25, 26, 27, 28

Table 13: Test Results of Samples with Rice Hulls and Wood Bark

Sample	(g/cc) Density*	Shore Hardness (D Scale)	Water Pick Up After 1 hr.(%)	Water Pick Up After 24 hrs.(%)	Shore D Hardness After 24 hrs. Immersion (wet)
29A	1.06	71	13%	23%	60
29B	1.10	64	21%	26%	60
29C	0.97	65	20%	26%	53
28A	1.03	70	23%	29%	50
28B	0.93	65	37%	39%	50
28C	1.09	66	21%	24%	58
28D	0.93	70	29%	34%	65
28E	1.04	75	14%	23%	60
24A	1.05	60	32%	42%	46
24B	0.99	68	17%	28%	62
24C	1.01	70	43%	50%	42
24D	0.93	72	28%	40%	54
24E	1.13	74	21%	43%	50
27A	0.98	60	18%	33%	47
27B	0.98	66	38%	42%	40
27C	0.97	65	40%	41%	48
27D	0.95	60	24%	34%	32
27E	0.99	72	13%	27%	50

* Calculated by weighing the samples and measuring their volume

Table 14: Test Results of Samples with Corncobs and Wood Bark

Sample	(g/cc) Density*	Shore Hardness (D Scale)	Water Pick UP After 1 hr. (%)	Water Pick Up After 24 hrs. (%)	Shore D Hardness After 24 hrs. Immersi (wet)
30A	1.25	60	20%	22%	46
30B	1.28	63	7%	15%	45
30C	1.07	71	9%	21%	67
26A	0.92	65	30%	48%	40
26B	0.99	60	51%	54%	40
26C	1.03	60	45%	47%	42
26D	0.99	68	41%	48%	40
26E	1.02	72	16%	29%	55
23A	1.29	64	9%	18%	68
23B	1.40	64	31%	36%	52
23C	1.19	58	24%	28%	57
23D	1.21	58	14%	22%	50
23E	0.96	58	16%	19%	68
25A	0.94	70	12%	25%	62
25B	1.08	70	12%	22%	64
25C	1.08	70	19%	25%	58
25D	0.90	70	23%	37%	52
25E	0.93	70	12%	24%	58

* Calculated by weighing the samples and measuring their volume

that the amount produced under the reflux system would be lower. This study was made to determine how much furfural was formed under different conditions, e.g. reaction time, change of catalysts and mechanical agitation.

The analytical method utilized was a sodium bi-sulfite titrimetric analysis (Appendix A) which was found satisfactory. Determinations were carried out on mixtures containing only rice hulls (Mixture YT-29) or ground corn cobs (Mixture YT-30).

The amounts of furfural produced as function of different reaction time are presented in Table 15.

Since it is reasonable to assume that the water contained in corn cobs is available for the reaction mixture. the yield calculations based on B are convenient. The most accurate method would involve water content on each batch of cobs used and yeild calculated according to C; however, this is more troublesome and unnecessary at present.

Rice hulls yield about 4% furfural after 20 hours. The amount produced from corn cobs can be calculated by three different methods. The reason for this is that fresh ground corn cobs contain about 60% water.

Dry corn cobs (wet corn cobs after standing 2 weeks at room temperature lost 60% weight of water) were hydrolyzed under the same conditions previously described. The amount of furfural found based on the weight of dry cobs was 6.6%. As the results derived from hydrolyzed wet corn cobs are not absolute, and yield of furfural was calculated based on different assumptions, it shows here that results on column C are closest to the results obtained by hydrolyzing dried corn cobs. It was also assumed that the drying of corn cobs at room temperature for two weeks did not impair their ability to produce furfural, although prior work indicated that corn cobs after standing for one year yielded less furfural than fresh cobs.

The effect of mechanical stirring during reaction on the amount of furfural produced was determined on a corn cob mixture (YT-30) after 20 hour reaction (See Table 16).

Table 16

Yield of Furfural With Aid of Mechanical Stirring

Method of Calculation	% Furfural
Based on wet corn cobs	3.03
Based on dry corn cobs (water of cobs included)	10.16
Based on dry corn cobs (water of cobs excluded)	7.58

Table 15
Effect of Reaction Time on Furfural Yield

Reaction Time (hr)	Corn Cobs A	Corn Cobs B	Corn Cobs C	Rice Hulls
3	0.19%	0.63%	0.42%	0.38%
10	0.74%	1.86%	1.20%	1.53%
20	3.26%	10.93%	8.16%	4.13%

A. Calc'd on wet corn cobs (as is)

B. Calc'd on dry weight, with water content of corn cobs included

C. Calc'd on dry weight of corn cobs

These results showed that mechanical agitation did not improve the yield of furfural. On the other hand, it was noted that the constant stirring breaks up most of the material into very small particles. It should also be noted that mechanical agitation makes the process more expensive because of the additional energy required.

Reactions were carried out on rice hulls (Mixture-29) and corn cobs (Mixture-30) by replacing hydrochloric acid with the exact volumes of sulfuric acid (concentrated). The reason for this experiment is the frequent mention of sulfuric acid used as hydrolysis catalyst in industrial production of furfural from corn cobs and other materials.

The results show that with rice hulls (reflux time 20 hours), the furfural produced is 3.45%, which is about the same as with hydrochloric acid.

In the case of corn cobs, the yield is about 50% lower than with hydrochloric acid (see Table 17).

Table 17

Yield of Furfural by Sulfuric Acid Catalysis

Method of Calculation	% Furfural
Based on wet corn cob	1.83
Based on dry corn cobs (water of cobs included)	6.12
Based on dry corn cobs (water of cobs excluded	4.57

All compositions discussed above were compression molded into flexure test specimens.

Mold: two cavity steel mold - each sample measured 1" x 6", average thickness 1/4". The depth of cavity is 1-3/4" because the bulk factor of these materials is 6. Two samples were molded simultaneously for each composition.

Drying: All compositions were dried over night at 40 degrees Centigrade (air circulating oven). Previous experience with partially-dried samples gave disastrous results, e.g. extensive delaminations, or charring of the material (probably by the acid present in the remaining water).

Molding: temperature: @ 150 degrees Centigrade, time at pressure: 20 minutes, pressure: 500 psi.

Test results are represented in Table 18 for rice hull mixtures and Table 19 for corn cobs.

The following conclusions were drawn.

1. Modulus of rupture increases with increased density. This is achieved in mixtures containing no wood bark (29 & 30), and in mixtures containing a high proportion of wood bark, rice hulls/wood bark, rice hulls/wood bark 100/75 (Mix-24), and corn cobs/wood bark 100/75 (Mix-23). Mix 26-E presents an exception to general findings.
2. The addition of newspaper did not seem to improve the modulus of rupture. In some cases it even caused lower density and lower strength, which might be partly explained by the blender shredding the material in order to get the paper evenly incorporated.
3. In most of the cases, the addition of furfural (samples designated-C), or addition of furfuryl alcohol (samples designated - D,E.) did not improve the strength.
4. Future work should concentrate on the processing of materials without the use of external binders. A complete summary of the rice hull specimens are presented in Table 20 and the corn cob specimens in Table 21.

TABLE 18: Rice Hull Based Compositions

Sample	Width (in)	Thickness (in)	Weight (g)	Density	Flexural load (lbs)	Modulus of Rupture (psi)
29A(1)	0.985	0.207	23.5	1.15	13.5	1918
29A(2)	0.985	0.207	22.9	1.12	12.5	1776
29B(1)	0.997	0.323	31.6	0.99	16.5	951
29B(2)	1.002	0.318	30.7	0.98	13.1	744
29C(1)	1.000	0.210	22.1	1.07	7.1	969
29C(2)	1.004	0.214	23.9	1.09	9.7	1272
28A(1)	0.985	0.222	21.5	0.98	7.5	913
28A(2)	0.985	0.218	20.8	0.97	5.5	694
28B(1)	1.000	0.350	34.9	1.01	20.0	980
28B(2)	1.000	0.346	34.4	1.01	26.0	1303
28C(1)	1.005	0.302	33.7	1.13	23.51	1538
28C(2)	0.996	0.290	30.7	1.08	21.51	1540
28D(1)	1.004	0.315	30.3	0.98	14.01	846
28D(2)	1.000	0.315	29.1	0.94	12.75	770
28E(1)	1.005	0.372	33.6	0.92	15.1	652
28E(2)	1.000	0.370	33.6	0.92	17.0	745
24A(1)	.995	0.260	27.2	1.06	16.1	1438
24A(2)	1.000	0.280	27.2	0.99	13.2	1014
24B(1)	1.000	0.330	34.1	1.05	17.5	964
24B(2)	1.001	0.340	37.7	1.12	16.6	862
24C(1)	1.001	0.322	32.5	1.03	14.7	853
24C(2)	1.000	0.317	32.5	1.04	14.5	866
24D(1)	1.002	0.317	30.8	0.99	14.7	879
24D(2)	1.004	0.317	30.6	0.98	14.7	877
24E(1)	1.007	0.373	33.5	0.91	12.4	530
24E(2)	0.998	0.372	34.0	0.93	18.2	575
27A(1)	1.003	0.298	29.1	0.99	9.5	640
27A(2)	1.000	0.292	28.0	0.97	8.5	598
27B(1)	1.002	0.321	31.4	0.99	13.0	755
27B(2)	1.006	0.320	31.5	1.00	14.7	859
27C(1)	1.001	0.356	34.4	0.98	10.5	496
C(2)	1.003	0.356	32.2	0.92	10.7	507
27D(1)	0.999	0.373	33.3	1.04	23.6	1020
27D(2)	1.002	0.377	37.8	1.02	23.0	969
7E(1)	1.006	0.344	33.1	0.98	19.5	983
(2)	0.999	0.341	33.6	1.00	18.9	975

TABLE 19: Corn-Cob Based Compositions

Sample	Width (In.)	Thickness (In.)	Weight (g)	Density	Flexural Load (lbs)	Modulus of Rupture (PSI)
30A (1)	0.994	0.180	19.3	1.09	8.0	1490
30A (2)	0.985	0.163	17.1	1.07	5.0	1146
30B (1)	0.985	0.212	25.3	1.12	9.0	1219
30B (2)	0.994	0.208	23.1	1.13	7.8	1084
30C (1)	0.985	0.190	19.7	1.04	8.4	1417
30C (2)	0.993	0.193	19.5	1.03	8.2	1320
26A (1)	0.996	0.254	24.7	0.99	8.4	781
26A (2)	1.000	0.255	24.8	0.99	8.4	775
26B (1)	1.000	0.290	27.5	0.96	10.7	763
26B (2)	0.994	0.285	27.3	0.97	10.7	790
26C (1)	0.999	0.255	25.7	1.02	12.5	1154
26C (2)	0.995	0.253	24.8	1.00	10.6	1001
26D (1)	0.999	0.282	27.5	0.99	15.5	1171
26D (2)	0.993	0.280	27.5	1.00	16.7	1291
26E (1)	0.998	0.310	29.4	0.96	18.9	1180
26E (2)	0.994	0.312	28.7	0.94	16.4	1010
23A (1)	0.995	0.228	25.2	1.12	14.0	1624
23A (2)	0.998	0.233	25.2	1.10	11.4	1258
23B (1)	1.000	0.235	24.9	1.08	10.7	1168
23B (2)	1.002	0.240	24.5	1.04	10.1	1052
23C (1)	1.003	0.237	25.2	1.08	10.6	1131
23C (2)	1.004	0.239	25.0	1.06	12.0	1255
23D (1)	1.000	0.284	28.6	1.02	18.2	1357
23D (2)	0.996	0.279	28.6	1.03	17.4	1344
23E (1)	0.996	0.286	29.2	1.04	18.4	1353
23E (2)	1.000	0.290	29.1	1.02	23.7	1694
25A (1)	0.997	0.299	27.2	0.92	8.0	538
25A (2)	1.000	0.296	27.2	0.93	7.4	505

Table 19: Corn-Cob Based Compositions (Cont'd.)

Sample	Width (In.)	Thickness (In.)	Weight (g)	Density	Flexural Load (lbs)	Modulus of Rupture (PSI)
25B (1)	0.998	0.306	28.9	0.96	9.9	634
25B (2)	1.004	0.310	28.9	0.95	8.7	544
25C (1)	0.999	0.298	28.2	0.96	9.7	659
25C (2)	1.000	0.299	27.9	0.95	11.6	780
25D (1)	0.998	0.321	29.9	0.95	12.4	722
25D (2)	1.000	0.322	29.9	0.92	13.0	752
25E (1)	1.000	0.370	31.7	0.87	12.6	553
25E (2)	0.998	0.370	32.6	0.89	13.4	587

Two-Step Process of "In-Situ" Formation of Furfural from Waste Without Additives

It was discovered that materials containing cellulose and pentosans when treated by acid, yield a binder during the process of molding (Figures 5 and 6). The initial work was conducted on wheat straw, rice hulls and corn cobs.

The acid treatment is very simple and inexpensive. Preliminary experiments used 3% solutions of hydrochloric or phosphoric acids. The material was soaked in the acidic solution for 30 minutes after which the solution was removed, and the material dried either at room temperature or oven dried at 50-60 degrees Centigrade.

More dilute solutions of hydrochloric acid or solutions of weak acids, e.g. boric acid, yielded no binder during the molding process. Other strong acids which are non-volatile were also evaluated now for this process; the prime candidate was p-toluenesulfonic acid.

The period of soaking in acid was arbitrarily fixed. A much shorter period of soakings might be found as effective.

It is believed that the proper balance between acid and water and waste material is very important for the final properties, and preventing void formation.

These materials have to be molded under pressure in order to yield useful products under the following conditions:

Temperature:	120-150 degrees Centigrade
Time:	5 minutes
Pressure:	500 psi

These parameters are believed to be general guidelines for such a process.

Moldings were carried out on a Carver laboratory press. The pressure decreased during the first 2-2.5 minutes of molding, after which there was very little loss of pressure.

A distinct smell of furfural was noted in the vicinity of the mold, while pressing. However, there is no flow of resin outside the sample.

Rice hulls and wheat straw were treated with the following acids as 3% solutions: oxalic acid, chromic acid, HCl + 1% $AlCl_3$ and p-toluene sulfonic acid.

Table 28
RICE HULLS/WOOD BARK
ACID HYDROLYZED

MIX		YT-29-A	YT-29-B	YT-29-C	YT-28A	YT-28B	YT-28C	YT-28D	YT-28E	YT-24A	YT-24B	YT-24C	YT-24D	YT-24E	YT-27A	YT-27B	YT-27C	YT-27D	YT-27E
Materials (Part by Weight)	Rice Hulls	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
	Wood Bark				15	15	15	15	15	22.5	22.5	22.5	22.5	22.5	30	30	30	30	30
	Con Hcl	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Water	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115
	Silacon #12	40	40	40	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
	News-Paper		15	10		10	16	16	16		16	16	16	16		16	16	16	16
	Furfural			5			8					8					8		
	Furfuryl Alc							8	16				8	16				8	16
Modulus of Rupture PSI		1030	847	1120	803	1141	1540	810	700	1220	910	860	878	550	620	800	500	995	980
Density (g/cc)		1.13	0.98	1.08	0.97	1.01	1.11	0.96	0.92	1.03	1.08	1.03	0.98	0.92	0.98	0.99	0.95	1.03	0.99
Water Pick Up 1 hour (%)		13	21	20	23	31	21	29	14	32	17	43	28	21	18	38	40	24	13
Water Pick up 24 hrs (%)		23	26	26	29	39	24	34	23	42	28	50	40	43	33	42	41	34	27
Shore Hardness (D)		71	64	65	70	65	66	70	75	60	68	70	72	74	60	66	65	60	72
Hardness After 24 hour Water Soak		60	60	53	56	50	58	65	60	46	62	42	54	50	47	40	48	32	50

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Table
CORN COBS/WOOD BARK
ACID HYDROLYZED

	MIX	YT-30-A	YT-30-B	YT-30-C	YT-26-A	YT-26-B	YT-26-C	YT-26-D	YT-26-E	YT-23-A	YT-23-B	YT-23-C	YT-23-D	YT-23-E	YT-25-A	YT-25-B	YT-25-C	YT-25-D	YT-25-E
MATERIALS (Part by weight)	Corn Cobs	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
	Wood Bark				60	60	60	60	60	90	90	90	90	90	120	120	120	120	120
	Con. HCl	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
	Water	200	200	200	200	200	200	200	200	200	200	200	200	200	220	220	220	220	220
	Silvacon 412	50	50	50	70	70	70	70	70	70	70	70	70	70	60	60	60	60	60
	Newspaper		33	22		38	38	38	38		40	40	40	40		44	44	44	44
	Furfural			11			19					20					22		
	Furfuryl Alcohol							19	38				20	40				22	44
Modulus of Rupture (PSI)		1318	1151	1368	778	778	1075	1231	1095	1441	20	1193	1350	1523	521	589	720	737	570
Density (g/cc)		1.08	1.12	1.03	0.99	0.96	1.01	0.99	0.95	1.11	.26	1.07	1.02	1.03	0.92	0.95	0.95	0.93	0.88
Water Pick Up 1 hr. (%)		20	7	9	30	51	45	41	16	9	31	24	14	16	12	12	19	23	12
Water Pick Up 24 hr. (%)		22	15	21	48	54	47	48	29	18	36	28	22	19	25	22	25	37	27
Hardness Shore D		60	63	71	65	60	60	68	72	64	64	58	58	58	70	70	70	70	70
Hardness, After 24 hr. Soak		46	45	67	40	40	42	40	55	68	52	57	50	68	62	64	58	52	58

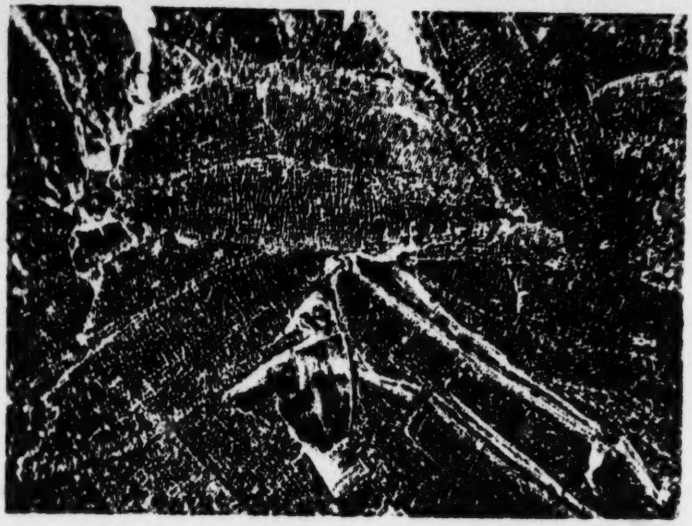

Figure 5: Molded Rice Hulls - without binder

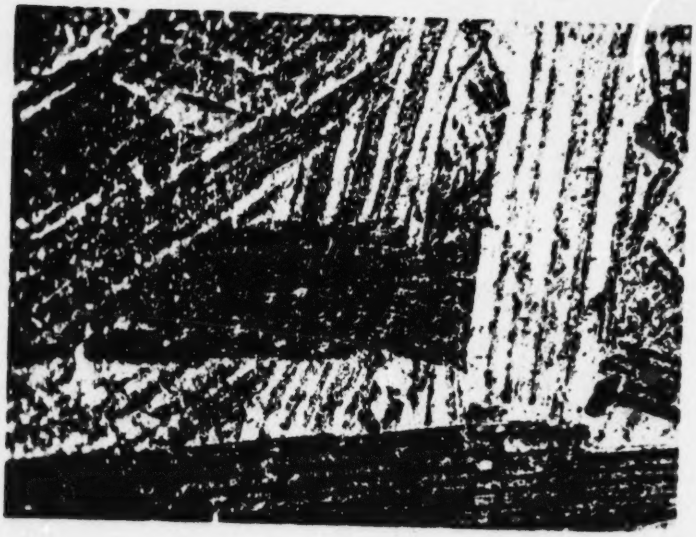

Figure 6: Molded Wheat Straw - without binder

Oxalic Acid and Boric Acid failed to catalyze binder formation with only mechanical debulking occurring.

Chromic Acid oxidized and burned the materials even before being pressed.

The combination of HCl and $AlCl_3$ also seemed to hurt both rice hulls and straw, by some charring and delaminations in the case of straw.

The best performance so far was by use of a 3% solution of p-toluene sulfonic acid, which is also non-volatile and non-corrosive to tools.

Some problems were encountered with wheat straw. Breaking down fiber size was carried out in a Waring blender, and there was a wide range of sizes. Some parts of straw have considerable amounts of pith (white foam material) and the action of the blender did not seem to remove this, and this subsequently caused retention of water, and delaminations of products. The presence of pith also had adverse effects when exposed in weatherometer.

Cotton waste was successfully molded with all three acids (HCl; H_3PO_4; p-toluene sulfonic); it seemed that the main source of binder was generated from dried stalks and flower pods. There may also be pentosan containing materials in cotton waste (perhaps in the stems and pods) which are absent in "refined" cellulose, e.g. newspaper, absorbent cotton or cotton cloth.

The reason for the last comment originated from experiments carried out with cotton wool, newspaper, and cotton cloth. These materials were treated as previously mentioned and molded under similar conditions. However, they just turned brown and seemed self-bonded without any binder formed during the molding process; this was also evident by the very weak nature of the products. Western hemlock wood bark behaved similarly under the same conditions, yielding a modulus of rupture of 407 psi, which indicated just self-bonding under heat and pressure.

Saw dust, white-pine shavings and alder wood shavings were initially used to determine the feasibility of this process for wood waste. Phosphoric acid gave excellent results with these wood wastes.

Further work was carried out on other types of wood, e.g. Ash, Redwood, and Douglas Fir. It was found that these responded to the acid treatment as well and gave moldable materials without the need of added binder.

Wood particles were obtained as a combination of dust and shavings from a neighboring carpenter, in order to get an idea how the size of particles effected properties. The material obtained was divided into three size categories:

"A"	Particles not passing through a 4-mesh sieve.
"B"	Particles passing through a 4-mesh sieve but not 8-mesh sieve.
"C"	All particles passing through a 4-mesh sieve.

The tabulated results indicated in most cases that category C gave best results. This could be explained by the fact that it included all fractions of 4 mesh, down to dust, which facilitate intimate contact of the particles. Accumulated data indicated that this intimate contact is a prerequisite for this process.

All treated samples were compression molded. Molding data and some properties were summerized in Table 22.

Additional samples molded under the same conditions were soaked for seven days in water at room temperature and the results summerized in Table 22.

All molded wood specimens and rice hull moldings were submitted to an accelerated weathering test, carried out in a Atlas Electric Weatherometer Model HVDL (details in Progress Report No. 5, Chapter 1). The samples were compared to commercial and industrial grade particle board (44 lb/ft^3 and 55 lb/ft^3 density respectively).

The above mentioned materials were not intended for external use, and exposure to outside weather. However, this type of test can be used as an accelerated screening and point out the compared durability of various materials.

The results are summerized in Table 22 and clearly show that the properties compare to those of commercial particle boards. Most samples with mixed size particles showed best surface condition after weatherometer test. The particle boards showed warpage and delamination. Exposed, coarse particle board surfaces showed flaking and were dehydrated.

It was previously described that either wood particles or rice hulls were treated in 3% acid solution at room temperature. The treatment period was arbitrarily picked as 30 minutes, which seemed to be more than necessary.

In order to carry out this process in industry, it is preferrable to investigate feasibility of shorter treatment periods, without loss of properties.

Some experiments were carried out with ashwood and rice hulls and the results are summerized in Table 23.

Ash, which is highly absorbent, could be treated at room temperature for as short as one minute. The strength properties of ash treated at higher temperature were improved but not to a great extent.

Rice hulls are not absorbent. Treatment at room temperature for short period (one minute) gave totally negative results. However, treatment at 60 degrees Centigrade for five minutes gave reasonable results, higher temperatures or longer treatment might even improve a little more.

The flammability of the following materials was determined.

A. Industrial grade particle board (55 lb/ft^3 - Density)

B. Molded rice hulls (YT-46)

C. Molded white pine (YT-58)

D. Molded Ash (YT-64)

The industrial grade particle board was taken as control. White pine and ash were selected to represent the various types of wood that could be processed under the same conditions, as mentioned in previous reports.

For flame spread, testing panels sized 4" x 6" (average thickness = 0.3") were molded and bonded at the width edge with resorcinol-formaldehyde cold-setting adhesive. A laminated wood strip was bonded to the back with a vinyl-type adhesive in order to hold the panels in place (total length 30").

Smoke density test specimens were prepared by cutting molded panel into standard size (3" x 3" nom.).

Flame spread test (3030 test) results are presented in Table 22. Specimens are shown in Figure 7. NBS smoke density test (using the American Instrument Co. smoke density chamber) results are presented in Table 22.

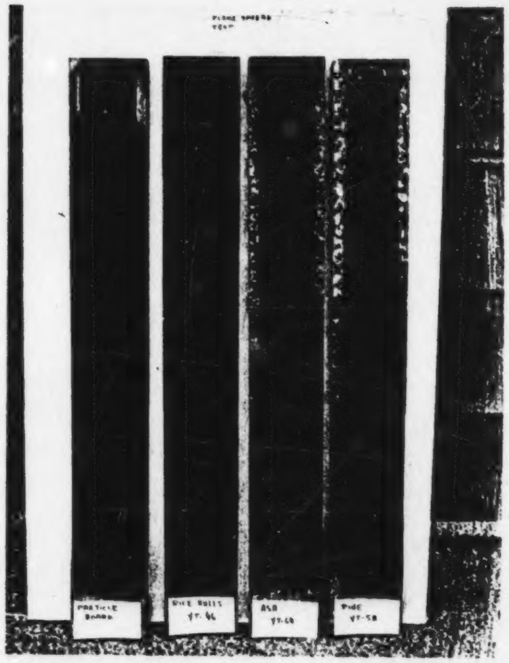

FIG. 7: Flame Spread Specimens, After Test

Flame spread results clearly show that industrial particle board is more flammable than the moldings without added binder. The least flammable is the product made from rice hulls. This behavior could probably be explained by the high silica content of the hulls. The molded woods contain small amounts of phosphoric acid which might be suppressing the flames. This is clearly shown by the zero flame-out time, as compared to particle board. The latter continued to burn and shortly after the burner was put out was engulfed with flames at all sides.

The smoke generated by the molded rice hulls was very low, probably because of the same reasons above. Again particle board gave the highest results, whereas, pine was somewhat reduced and ash much more so.

The above result indicates that molded rice hulls could be used for purposes where better fire properites are required. The other molded woods, although showing self-extinguishing properties, could be categorized at the same level as industrial particle board.

Molded wood waste and rice hulls without external binder are less flammable initially than commercially available particle board. However, further reduction, if achieveable, would have been desirable.

In this study, boric acid, sodium borate, or zinc borate were incorporated into the acid treating solution. Table 24 summarizes the results.

Materials including boric acid were the only ones properly moldable but with considerable loss in strength. There were reductions of 50% for rice hulls and over 60-70% for pine wood.

The reason for this strength reduction might be that each of the above mentioned additives impaired the binder formation; zinc borate may have even prevented it, although not altering the ph of the treating solution.

The nail and screw retention of the wood waste moldings were conducted to determine material workability. The results were at the same level as those for industrial particle board. This combined with the fact that these products have higher modulus of rupture, means they can be used for the same purposes as particle boards in current production.

Rice hulls moldings showed inferior nail and screw retention and if used, these facts have to be taken into consideration. The lower results for rice hulls are probably due to their non-fibrous, brittle characteristics. Perhaps this can be improved by addition of some sibrous material. Test results are summarized in Table 22.

The tests were carried out according to ASTM D-1037 -"General Methods for Evaluating the Engineering and Design Properties of Wood-Base Fiber and Particle Panel Materials".

Sections 47-53: Nail Withdrawal Test
Sections 61-67: Direct Screw Withdrawal Test
(Test carried out on dry samples only, face side.)

Molded panels 4" x 6" x 0.3" were bonded together to increase thickness, by a vinyl type adhesive. Industrial particle board (55 lb/ft^3) was used as control. Two panels used for nail withdrawal and four panels for screw withdrawal test.

Molded wood waste and rice hulls, without external binder, showed good mechanical properties when molded at pressures higher than 300 psi. Best results were obtained in most cases when pressure was 500 psi. This is probably due to the fact that the binder is formed, polymerized and cross-linked by intimate, high pressure contact of the particles.

It was thought that the addition of external binder might reduce the need for high pressure. This binder should be reactive at low pH and be non-expensive.

Table 22
PROPERTIES OF MOLDED MATERIALS WITHOUT EXTERNAL BINDER

Material No.		YT-26	YT-58-C	YT-61-C	YT-63-C	YT-64-C	YT-33	YT-49	YT-51	
Waste Material		Rice Hulls	Pine	Alder	Redwood	Ash	Corn-cobs/ Rice Hulls	Wheat Straw/ Rice Hulls	Cotton Waste	Ind. grade particle boa
Acid		p-toluene Sulfonic	Phosphoric Acid	Phosphoric Acid	Phosphoric Acid	Phosphoric Acid	Hydrochloric Acid	p-toluene sulfonic acid	Phosphoric Acid	-
Molding (0.2" thick)	Temp. °C	150	150	150	150	150	150	130	150	-
	Time (min.)	5	3	5	3	3	5	5	8	-
	Pressure (PSI)	500	500	500	500	500	500	500	500	-
Density (g/cm^3)		1.08	1.06	1.03	1.11	1.02	0.95	1.14	1.09	0.88
Modulus of Rupture (PSI)		1322	2297	2148	3236	3188	1034	1965	1327	1500
Straight Nail Pull (lb.)		13	39	-	-	67	-	-	-	56
Straight Screw Pull (lb.)		130	252	-	-	378	-	-	-	296
Blame Spread		58	95	-	-	123	-	-	-	127
Smoke Number		51	315	-	-	198	-	-	-	345
Water Soak (7 days)	% weight gain	27	23	39	54	29	-	-	-	64
	% thickness gain	13	12	21	11	9	-	-	-	22
Hardness Shore(1)	Before Test	64	75	64	71	60	-	-	-	70
	After Test	55	40	36	63	58	-	-	-	50
Weather-Ometer (350 hrs)	% weight loss	17	18	20	17	30	-	Badly weath. *	Badly weath*	14
	% thickness gain	27	4	25	3	4	-	Warped fibers exposed	and swelled	22
Hardness Shore(1)	Before Test	63	79	65	75	79	-	-	-	70
	After Test	35	41	22	58	27	-	-	-	50

* Exposed only 115 hours.

Table 23
Ash and Rice Hulls, Acid Treated for Short Periods

Sample	Material	Acid Treatment Time (Min.)	Acid Treatment Temp (°C)	Molding Time (min.)	Molding Temp (°C)	Molding Pressure (PSI)	Density	Modulus of Rupture (PSI)
YT-64	Ash + 3% H_3PO_4	1	24	3	140	300	0.79	1205
YT-64	Ash + 3% H_3PO_4	1	24	3	140	500	1.08	2023
HT-64	Ash + 3% H_3PO_4	1	80	3	140	300	0.78	993
YT-64	Ash + 3% H_3PO_4	1	80	3	140	500	1.10	2570
YT-46	Rice Hulls + 3% p-toluene Sulfonic Acid	1	24	5	140	500	*	*
YT-46	Rice Hulls + 3% p-toluene Sulfonic Acid	5	60	5	140	500	1.10	1308

* Dry, falls apart, no resin formed.

These experiments clearly demonstrate the feasibility of industrial processing. In any specific case, optimal treatment parameters should be investigated., depending on the types of wood and particle size distribution.

Table 24: Molded Wood Waste and Rice Hulls with Fire Retardants
Molding: 5 min./150°C/500 psi

Mix	YT-46-B	YT-58-B	YT-74	YT-75	YT-76	YT-77	YT-78	YT-79	YT-80	YT-81
Raw Material	Rice Hulls	Pine	Rice Hulls	Rice Hulls	Pine	Pine	Rice Hulls	Rice Hulls	Pine	Pine
Treatment Mix (Pbw)										
Water	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Phosphoric Acid		30			30	30			30	30
P-toluene Sulf. Acid	60		30	30			30	30		
Boric Acid			10	20	10	20				
Sodium Borate	30	30								
Zinc Borate							10	15	10	20
pH of solution	2-3	2-3	2-3	2-3	2-3	2-3	2	2	2	2
Modulus of Rupture (psi)	(1)	(2)	711	653	727	561	(2)	(2)	(2)	(2)

(1) Part well molded, but leaches out in water, and falls apart.
(2) Not moldable - falls apart on removal from mold.

Two potential binders were evaluated.

1. HT-115 (ITT Rayoner) - this is a Western Hemlock bark extract, a mixture of the sodium salts of flavanoid polymers that is used to extend cold setting resorcinol-type wood adhesives.

2. Raylig - Al (ITT Rayoner) - this is a Ammonium ligno sulfonate, with sugars, a by-product of wood processing.

HT-115

This resin dissolves in water and precipitates under acidic conditions. Wood particles and rice hulls were soaked in 10% solution of HT-115, excess decanted off and the particles dried.

A second soak was carried out in 3% phosphoric acid solution, excess was decanted off and the particles dried.

The particles were molded at 150 degrees Centigrade, 500 psi pressure, for 5 minutes. Rice hulls were very dry. A weak bond was formed between the hulls, and the molded part broke very easily. Molded Ash particles, that received the same treatment, also was dry and modulus of rupture dropped to 800 psi instead of 2400 psi and more without incorporation of HT-115.

Raylig-Al

Various tests were carried out to determine the most efficient way to impregnate the particles with this binder. Either before the acid treatment or simultaneously. This binder by itself was very soluble in water, even after drying and heating at temperatures higher than 100 degrees Centigrade. However, a drastic decrease in solubility was noted when pH was lowered. Its own 10% solution has @ pH-4.

Finally, a treatment process was carried out by a combined solution of 20-25% Raylig-Al and 3% phosphoric acid for wood particles, and the same with 3% p-toluene sulfonic acid for rice hulls. The treated particles were dried at room temperature and molded at 150 degrees Centigrade between 3-5 minutes under 500 psi pressure. Craft paper (5 mil. thick) was impregnated with a 50% solution of Raylig-Al and 3% phosphoric acid and air dried. The impregnated paper was molded as skin with wood particles, a glossy, scratch-resistant skin was formed.

Modulus of rupture for Redwood was in the same range as for particles treated with acid only. Rice hulls on the other hand showed 30% improvement in strength. However, when those molded specimens were put into water, some of the Raylig-Al slowly leached out. The moldings softened and were easily broken.

This binder work was discontinued mainly because of the rapid strength loss in water.

INORGANIC MATRIX MATERIALS

The studies in this task involved two types of matrices and two types of composites. The matrices considered were an MSC inorganic matrix derived from magnesium oxychloride and sulfates and various classes of commercial plasters. The MSC system is more expensive than plaster but is stronger and more resistant to environmental effects. The plaster systems are less expensive and more processable but must be protected from moisture.

Unlike the organic material, an elemental panel of an inorganic system does not offer a product. Instead, the materials had to be directed towards a functional application. All such applications require at least two elements. One element is a high density surface for strength, wear, and appearance and the other is a low density core for stiffness, weight reduction, insulation and cost. Therefore, this program developed a high density structural composite defined here as a laminate and a low density core composite defined here as a foam. Each of these are discussed in detail below.

Laminate Development

Magnesium oxychloride from which the MSC inorganic matrix is derived has been used for many years for the construction of floors and exterior stucco surfaces. It is a fire-proof, hard ceramic-type material with an unusual ability to absorb energy in a manner similar to plastics. In addition, it is low cost, plentiful and simple to process MSC initiated work on this system prior to this study to make the necessary modifications required for an efficient matrix.

The material is a water base system which requires the removal of the water to effect a "cure". MSC initiated this work by producing inorganic laminates on their continuous processing machinery. Glass fibers were used as the reinforcement. The material was deposited on a tray and allowed to "cure" at room temperature overnight. One half was covered with an impermeable Mylar film. The panel was then removed and permitted to continue its curing at room temperature for 28 days. Tests were made at 6, 11, 18 and 28 days. The uncovered part developed its strength within 6 days. Figure 8 presents this data. The higher values for 6 and 11 days is questionable and can probably be atrributed to test scatter.

This study shows it is feasible to process the inorganic matrix in a continuous manner when a faster cure is developed.

Reinforcing studies with the laminate included rice hulls, wood, Silvacon, paper, straw, and cotton waste as well as commercially available glass fibers. The glass fibers provide such superior strength that on a performance-cost basis the other reinforcements could be disregarded. Systems such as paper which deteriorate with water proved to be completely unsatisfactory. Since, as we will demonstrate later, the laminate is a very small part of the inorganic product, a limited utilization of an inexpensive commercially available material was considered consistent with the program study.

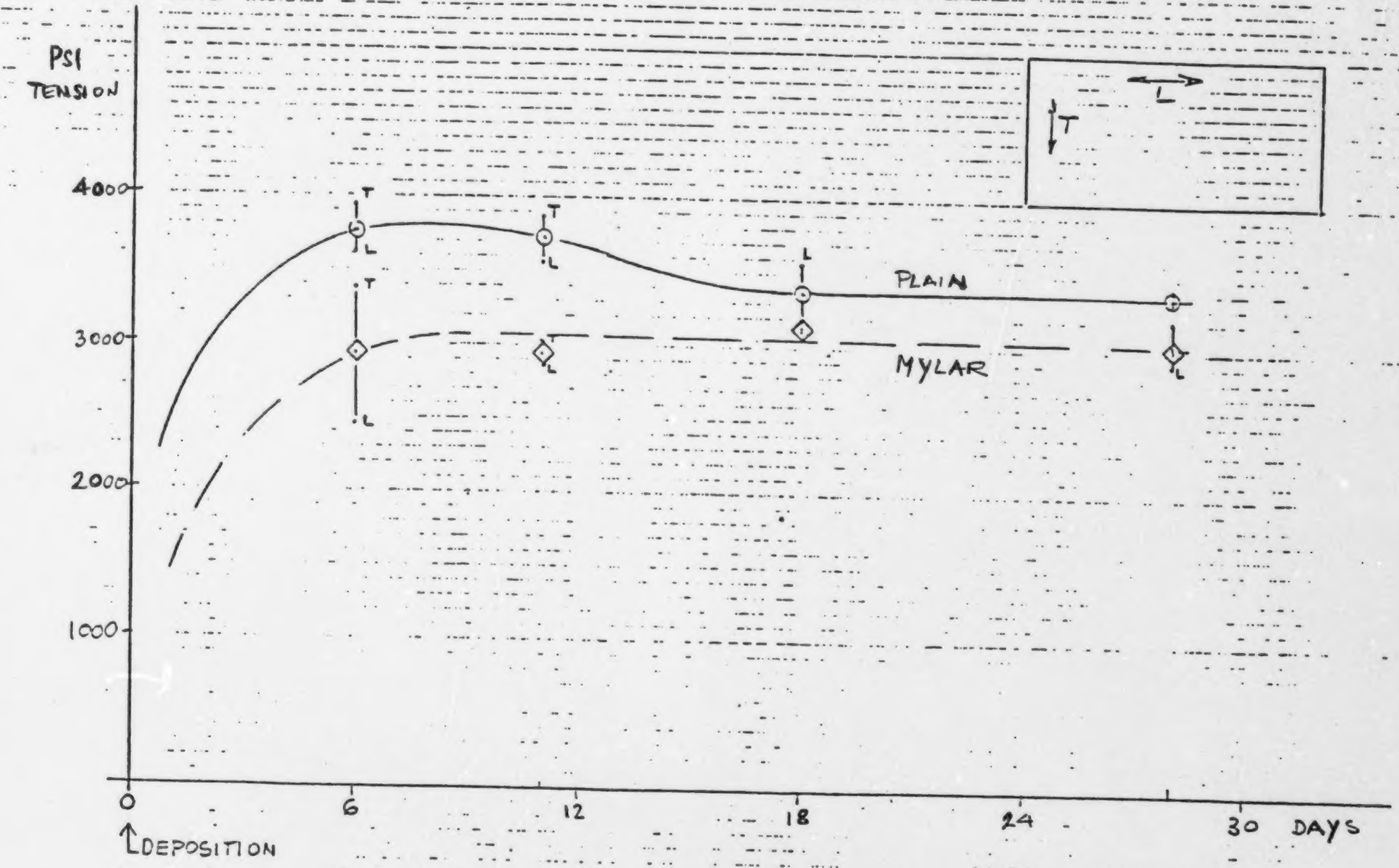

Figure 8: TENSILE STRENGTH OF MACHINE DEPOSITED LAMINATE

The first study conducted was to determine the effect of fiber length on the strength of an inorganic laminate. The tensile values were recorded in pounds per inch of width. Therefore, variance in thickness would not be accounted for. This results in more apparent test scatter than actually exists. Figure 9 shows the effect of fiber length. As can be seen, the longer the fiber the more the strength. Two inches is the practical limit for processing. The superiority of a two-inch fiber is further demonstrated in Figure 10 which evaluates the effect of fiber content. Since the interfacial shear strength of the inorganic matrix is low compared to that of a polyester, a longer fiber would be expected to develop greater strength.

On an analytical bases, a higher fiber content should develop greater strength. However, under certain processing conditions and with certain matrices, a saturation point is developed where additional fibers provide limited improvement. As demonstrated in Figure 10, this is not the case with a glass reinforced inorganic composite. The strength is still rising as a direct function of glass content at 22.3%. The strength developed at 20%, as will be shown later, is more than adequate for most construction requirements.

A variety of other processing parameters were evaluated. These parameters include the various sources for magnesium oxide and for magnesium chloride and fiber finish. The results are summarized in Table 25. Bare glass "AB" appears to provide the best interfacial strength.

The susceptibility of these materials to moisture attack was also evaluated. A laminate was exposed to the water immersion cycle defined in Table 26. The results showed deterioration of both strength and stiffness. A variety of organic polymers were then incorporated into the inorganic matrix to attempt to improve moisture resistance. The results are presented in Table 27. The next stop was to evaluate surface seals. The type of seals and the results are presented in Table 28. Alkyd paint demonstrated the best performance. This lead to further tests with Alkyd paint with the results presented in Table 29 showing that Alkyd will provide an acceptable protection if maintained on the surface.

Figure 11 presents the relationship of tensile stress to strain for the inorganic laminate. The relationship is much like that of metals. There is a clearly defined elastic region with a yeild point followed by a very long plastic region. This type of characteristic is particularly good for building construction. If the yield point is exceeded, there exists a very long period of deformation before failure. This period permits corrective action to be taken on the building before failure occurs.

In summary, these materials demonstrate highly desireable building properties because in addition to the above capabilities, the material will neither burn nor smoke when subjected to a fire. The material is also inexpensive and is in abundant supply.

Foam Development

The first acitvity initiated was on the development of a medium density foam. The initial intention was to develop a direct wood substitute.

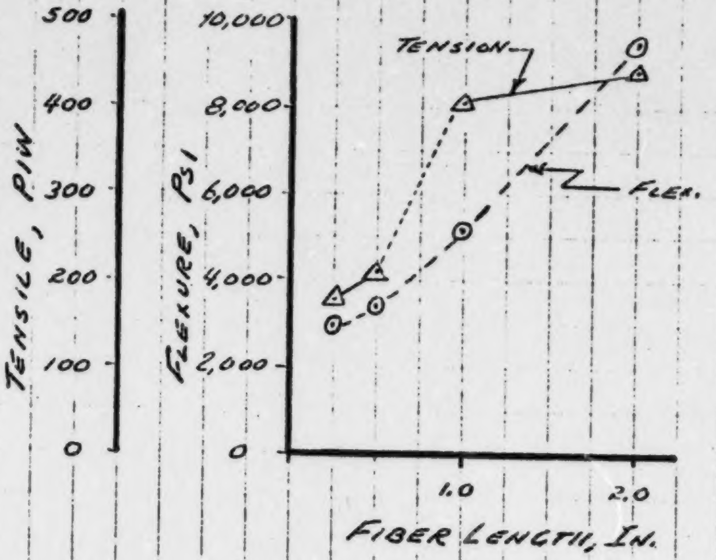

FIGURE - 9

EFFECT OF FIBER LENGT.

FIGURE ~ 10

EFFECT OF GLASS CONTEN

AND FIBER LENGTH

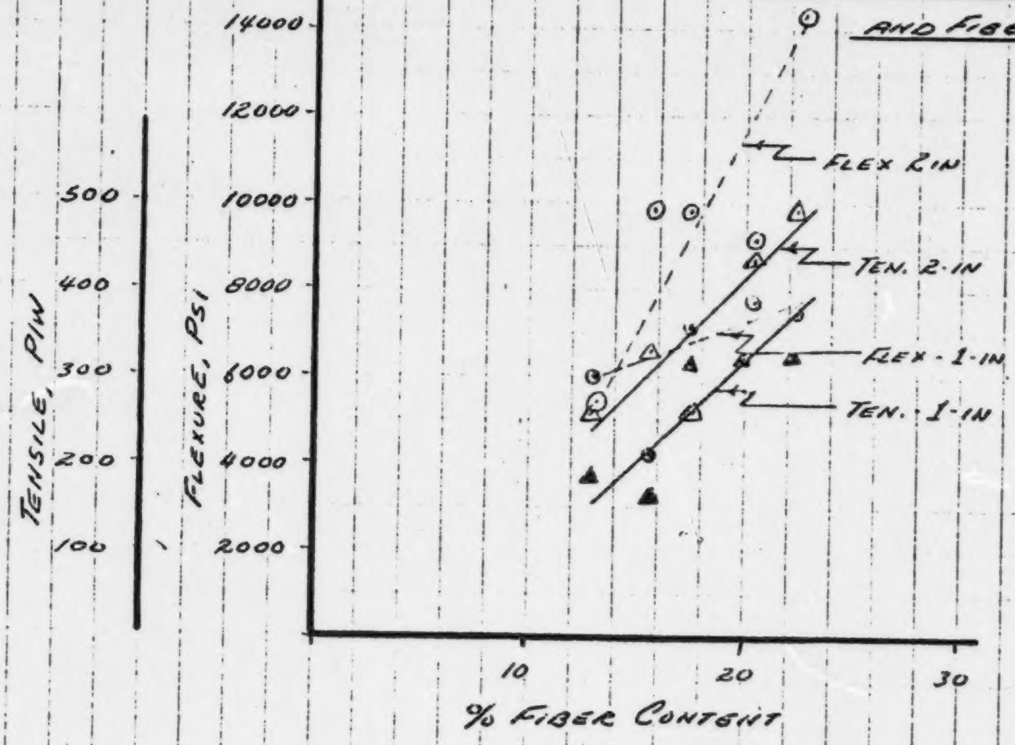

TABLE 25

VARIOUS PARAMETERS IN INORGANIC LAMINATE FABRICATION

Glass Content = 15%

Parameter	MgO	$MgCl_2$	Glass		Control	Flex After 24 hour Soak	
$MgCl_2$ Source			Length	Finish	Flex	Dry	Wet
	Mined	FMC	1/4"	AB	6000		
	Mined	DOW	1/4"	AB	6400		
	Mined	FMC	1/4"	DC	2600		
	Mined	DOW	1/4"	DC	3900		
	Mined	FMC	Mat.	Silane	13500	10600	4400
	Mined	DOW	Mat.	Silane	13400	11900	5900
	Sea	FMC	Mat.	Silane	16300	9800	3400
	Sea	DOW	Mat.	Silane	21900	9000	5800
Glass Finish	Mined	FMC	1/4"	AB	6000		
	Mined	FMC	1/4"	DC	2600		
	Mined	DOW	1/4"	AB	6400		
	Mined	DOW	1/4"	DC	3900		
	Mined	DOW	1/4"	AB	8230	4140	2630
	Mined	DOW	1/4"	DC	3970	2830	1630
	Mined	DOW	1/4"	AB	7185	4240	2330
	Sea	DOW	1/4"	AB	7360	4420	4680
	Sea	DOW	1/4"	AB	6830	5570	2400
	Sea	DOW	1/4"	DC	5300	2930	2200

TABLE 26

ENVIRONMENTAL RESISTANCE OF INORGANIC LAMINATES EXPOSED TO SIX COMPLETE CYCLES DURING THREE WEEKS

	Tensile Strength psi	Young's Modulus psi x 10^6	Wt. Loss
Control	3280	1.7	-
Exposed	1810	0.54	17.3%

Exposure Cycle:

A. Total Immersion in H_2O at 120°F, 1 hour
B. Water Spray at 160°F, 3 hours
C. Exposure to 14°F, 20 hours
D. Exposure to 160°F, 3 hours
E. Water Spray at 160°F, 3 hours
F. Exposure to 160°F, 18 hours

TABLE 27

USE OF ORGANIC POLYMERS FOR IMPROVED WATER RESISTANCE

Emulsion cont'g. 0.5% Resin 15% glass Flexural Strength

Composite	Dry	Wet
Control	6970	1180
+ PVAC	7800	1180
+ Resorcinol-Formaldehyde	7400	1060
+ Polyester	7700	1580
+ Polyurethane	7730	1640

TABLE 28

SEALANTS

COMPOSITES CONTAINING 15% GLASS, WATER SOAKED 24 HRS.
FLEXURAL PROPERTIES GLASS MAT 15% BY WT.

Sealant	Initial	Soaked
Thompson Water Seal	8450 psi	2825 psi
Sodium Carbonate	6450	1900
Interior Flat Latex	8025	1550
Sodium Hexametaphosphate	8775	1625
Vinylacrylic Paint	8700	2075
Exterior Alkyd Paint	11675	7375
A-1 Latex	8725	2550
Orange Shellac	9100	4925 poor adhesion
Rubber-Base Latex	9650	1950
Swimming Pool Paint	8250	5700 poor adhesion
Spar Varnish	10200	5300 poor adhesion
Lacquer	11675	5650 poor adhesion

TABLE 29

AGING IN H_2O USING EXTERIOR ALKYD PAINT

5:1:17 Composites Containing 15% Glass. Soaked in H_2O Various Times

FLEXURAL PROPERTIES

	24 Hrs.	72 Hrs.	144 Hrs.	30 Days
Control	8790	9810	9930	11300
Wet	6690	8570	7420	7590
Dry	7540	9930	6690	7930
7:1:11				
Control	13760	13030	11920	16150
Wet	10620	11230	9140	4860
Dry	11720	12730	10040	5840

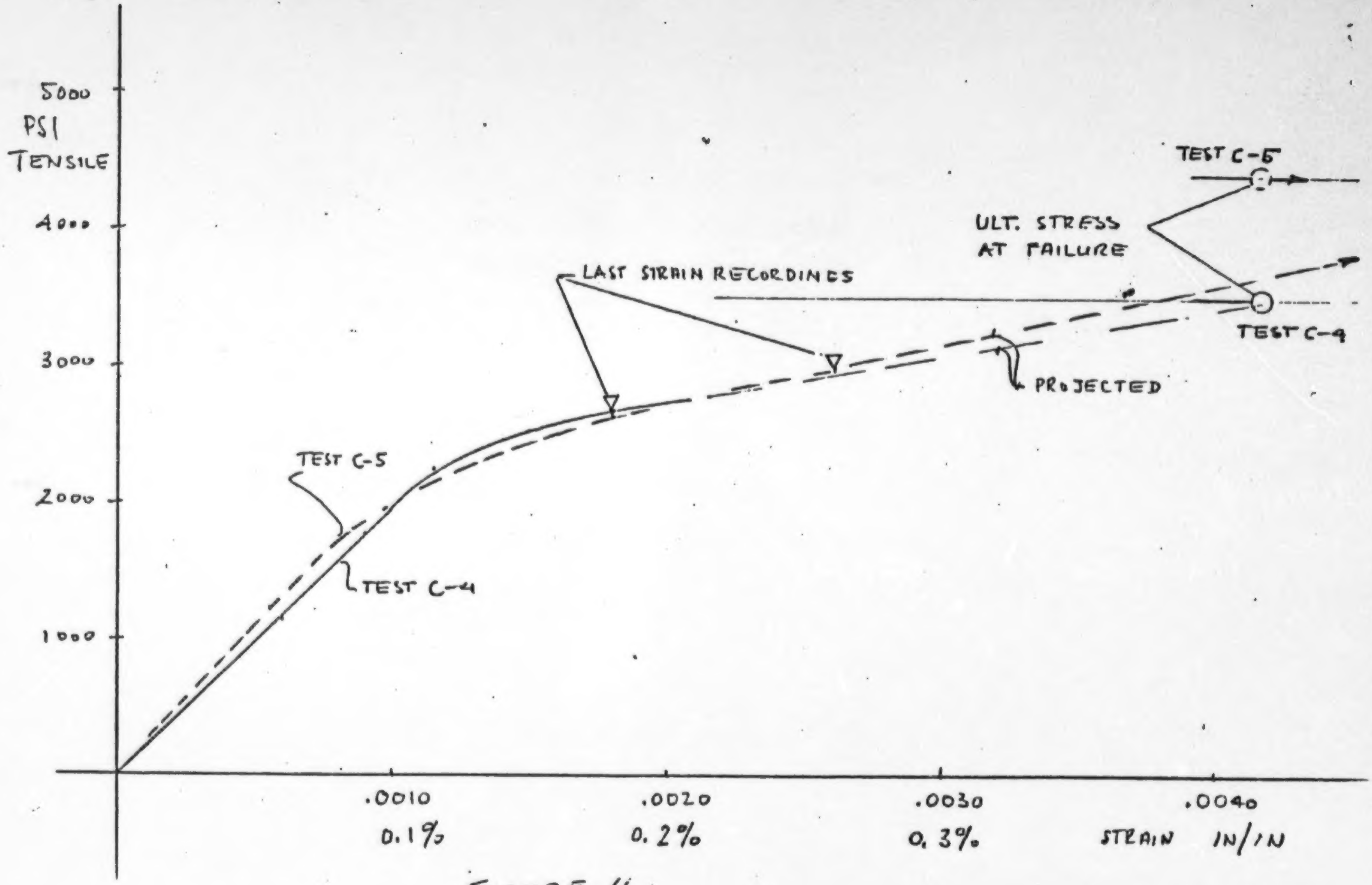

FIGURE 11

GLASS FIBER REINFORCED
INORGANIC MATRIX COMPOSITE
(DRY)

4.30.74 BL

It was most desirable that such a composite be non-flammable, have the same cost or less than wood and possess structural properties. In the event that wood properties could not be duplicated, there is an increasing need for non-burning furniture materials to replace the flammable materials now in use.

Magnesium oxychloride has been used for many years to prepare floors and stucco-like exteriors. It is a fire-proof, hard ceramic-like material with unusual ability to absorb energy in a manner very similar to that of plastics. It has the additional attributes of low cost and simple processing. Casting plaster is less expensive and can be processed as easily.

Initial formulation attempts indicated that it appeared possible to make a composite material which could retain nails and screws, could be sawed and would accept the shock impact of a hammerhead without damage. Magnesium oxychloride and casting plaster was used as the matrix material and fillers and reinforcements included rice hulls, cotton waste, scrap styrofoam, electric hopper fly-ash, Silvacon 412 and 1/4" ghopped glass. The scrap styrofoam was obtained from a processor who grounded rejected parts in such a manner as to tear the beads into irregular shapes and release the contained gas. In this form, the styrofoam provides improved properties over regular styrofoam beads probably by mechanical gripping and interlocking. The electric hopper fly-ash was supplied by the Environmental Protection Agency. Silvacon 412 is a Douglas Fir Bark Fiber by-products which has an interesting needle-like cystalline form and consists of almost equal parts of cellulose and lignin. The geometry of the Silvacon can contribute to toughening of brittle materials.

Rice hulls are a voluminous filler with an apparent density of about 0.125 g/cm^3 so that any material containing rice hulls will have this minimum density; any additional material that will fill voids between the hulls serves to increase the apparent density.

Most construction systems use 2 x 4 wood profiles for door and window framing. These wood profiles can warp and pose problems, therefore a light, inexpensive non-warping, and nailable substitute was sought.

The mixtures were packed into channels (3'5" wide x 1-3/8" deep). These beams are usually used as covers for 2" x 4" profiles on floors and door/window framing (see Figure 12). Two types of nail retention tests were carried out.

Type 1: straight nail pull.

Depth of nail insertion: 1-3/8" deep.
Nail measurements: steel wire, 2" long. 0.116" outer diameter, 20 rings/inch-test speed: 0.2"/minute.

Type 2: bending nail pull. 1/16" steel strips.

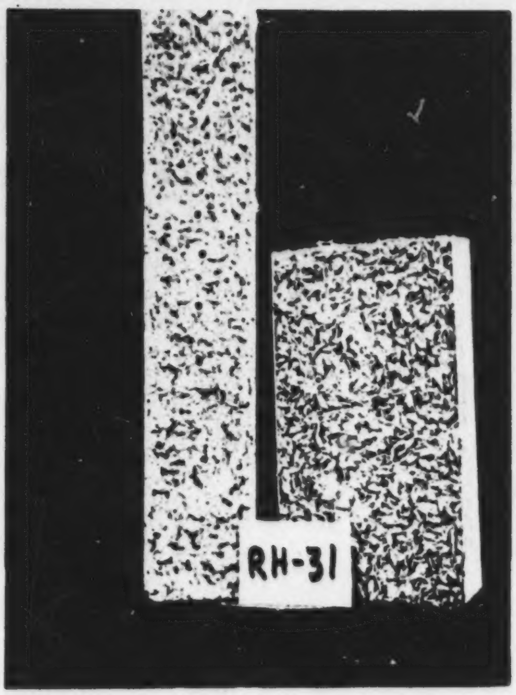

Figure 12: Nailable Products made with Rice Hulls

Nail type: 8 penny nail.
Depth of nail insertion: 1-3/8" (from bottom) and all the way from the side.

Speed of test: 0.2"/minutes.

The Type 2 test simulated actual conditions for these materials, and was thus performed only on those mixtures that gave best results in Type 1 test.

Table 30 presents a summary of formulations for nailable compositions. It also presents nail retention test results. In all compositions the rice hulls reinforcement (dry fraction) is premixed and binder-filler (wet fraction) separately premixed.

In the above studies, glass fibers were used to reinforce the composite. Wheat straw was evaluated as a replacement. The various formulations are summarized in Table 31. Three main effects were noted:

a. Increased difficulty to mix was noted as the straw proportion increased.

b. Final density was reduced by as much as 17% (as compared to materials with fiberglass).

c. Nail retention was reduced by as much as 40%.

Using RH-31 as reference, the effects of increasing the amounts of plaster and glass fibers on nailability was evaluated. Increasing the plaster increased the density and had no effect on the nail retention.

Increased amounts of 1" glass fibers reduced density and increased nailability but mixing became more difficult. Dry and wet mixing were carried out with a jiffy mixer causing no significant changes from hand-mixed materials.

To overcome the above-mentioned mixing difficulties, 1/4" glass fibers (with finish) were added and the main contribution was density reduction with no increase of nailability. The results are summarized in Table 32.

The casting plaster reacts fast reducing process time. Therefore, an evaluation of the gypsum plaster was made.

The effect of combined gypsum plaster/casting plaster on set, hardening time, density and nail retention is presented in Table 33.

Introduction of as much as 15 parts of gypsum plaster caused hardening retardation by over two hours. Mixtures containing casting plaster only hardened after 10 minutes.

Gypsum plaster when used alone gave substantially reduced nailability and lower density.

The application of the above studies are discussed in more detail in the Product Section.

TABLE 30: Formulations and Nail Retention of Nailable Wood-Placement Compositions

Component / Mix	RH-21	RH-26	RH-27	RH-28	RH-29	RH-30	RH-31	RH-32	RH-33	RH-34	RH-35	RH-36	RH-3
Rice Hulls	100	50	100	100	100	100	100	100	100	100	90	80	70
Styrofoam(beads)		25(1)									5	10	15
1" Glass Fibers (636AB)	5	5	5			5	5	5	5	5	5	5	5
Cotton Waste				10	20								
Proprietary Binder	40	40	40	40	40	40	40	40	40	40	40	40	40
Water	130	200	200	160	200	200	200	200	260	260	250	240	240
Casting Plaster		150	200		200	250	300	200	200	100	300	300	300
Fly Ash	200	150		200				50	100	150			
Density	0.35	0.58	0.58	0.38	0.53	0.64	0.69	0.64	0.61	0.47	0.70	0.64	0.61
Nail Retention Type 1- Top: (lbs.)	16.0	20.6	8.3	10.6	8	18.6	34.6	11.3	14.6	6.6	15.0	20.0	13.6
Bottom: (lbs.)	20.6	19.3	14.3	15.6	15.6	24.0	51.0	23.6	17.6	10.6	22.6	24.0	18.6
Nail Retention Type 2 (2)													
Bottom (lbs)							195				225	220	215
Side (lbs)							225				190	210	180

Notes: 1) for this formulation styrofoam was shredded waste beads.
2) all results in type 2 test were recorded when nail started cutting along the beam, no nail was pulled out.

Table 31: Nailable Materials Containing Straw

(Parts by Weight)

Mix Component	RH-38	RH-39	RH-40	RH-41	RH-42	RH-43	RH-44
Rice hulls	75	50	25	75	50	25	75
Wheat straw	25	50	45	25	50	75	25
Binder (MSC proprietary)	40	40	40	40	40	40	40
Casting plaster	200	200	200	300	300	300	150
Water	150	150	150	220	220	220	220
Fly Ash							150
Density (g/cm^3)	0.42	0.45	0.42	0.56	0.59	0.57	0.49
(lb./ft.^{3})	26.3	28.2	26.6	35.4	36.8	35.8	30.9
Nail Retention (1)	13	13	17	24	24	33	13
Top	9	12	19	17	30	35	14
(lb.)	10	26	13	29	32	31	16
Average	10.6	17	16.3	23.3	28.6	33	14.3
Bottom	23	19	24	24	33	26	21
(lb.)	15	18	20	31	25	35	25
	11	22	40	25	37	24	22
Average	16.3	19.6	28	26.6	31.6	28.3	22.6

(1) Type 1 test, straight nail pull

Table 32: Nailable Materials With Increased Amounts of Casting Plaster and Glass fibers

(Parts by Weight)

Component \ Mix	RH-45	RH-46	RH-47	RH-48	RH-49	RH-50
Rice hulls	100	100	100	100	100	100
1" glass fibers (636 AB)	5	5	10	15	5	5
¼" glass fibers (636 AB)					5	10
Binder (MSC proprietary)	40	40	40	40	40	40
Casting Plaster	350	400	300	300	300	300
Water	230	260	200	200	200	200
Density (g/cm^3)	0.66	0.74	0.58	0.60	0.61	0.61
(lb./ft.^{3})	41.7	46.1	36.5	37.4	38.3	38.4
Nail Retention (1)	30	50	41	55	38	50
Top	45	45	43	70	30	52
(lb.)	24	40	23	90	30	26
Average	33	45	35.6	71.6	32.6	42.6
Bottom	95	35	50	62	31	38
(lb.)	30	50	42	77	45	28
Average	56.6	38.6	38.6	63	35	31

(1) Type 1 test: straight nail pull

Table 33: Nailable Materials Containing Gypsum Plaster

(Parts by Weight)

Component / Mix	RH-51	RH-52	RH-53	RH-54	RH-55
Rice hulls	100	100	100	100	100
1" glass fibers (636AB)	15	15	15	15	15
Binder (MSC proprietary)	40	40	40	40	40
Gypsum plaster	300	150	75	60	45
Casting plaster		150	225	240	255
Water	200	200	200	225	225
Hardening time	hard but not dry after 20 hr. R.T.	same as RH-51	hard but not dry 3 hr. R.T.	hard & dry after 2¼ hr.R.T.	hard & dry after 2 hr. 10 min at R.T.
Density (g/cm^3)	0.62	0.71	0.62	0.65	0.65
($lb./ft.^3$)	39.1	44.5	38.7	40.9	40.5
Nail Retention (1)	34	45	55	51	44
Top	26	69	62	26	45
(lb.)	31	44	35	46	46
Average	30.3	52.6	50.6	41	45
Bottom	25	73	46	32	47
(lb.)	24	53	49	48	40
Average	26.6	55.3	44	41.6	41

(1) Type 1 test: straight nail pull (see Progress Report No. 4, p. 21)

A unique quality of these materials is its fire resistance and low smoke generation. This combined with the low density indicated that these materials might be good insulators.

The criteria for choosing matrix binders for this application were as follows:

1. Inexpensive.
2. Efficient - as little should be used to give sufficient bonding.
3. Water dispersible or emulsible.
4. Matrix binder should preferably harden by driving out the water.

The following matrix binders have already been tried out:

a. Water Glass (Sodium Silicate) - hardens at room temperature but needs further treatment to render it insensitive to water, a potentially good binder. Only preliminary work has been carried out with this material and further work will be pursued.

b. Acrylic Latex - (Acrycite Latex house paint ext/int A-1 paint and varnish corp./Torrance, California). This material is water emulsified, highly loaded, and supposed to have good bonding properties; however, the final product just wouldn't dry out, and fell apart when taken out of the mold.

c. Wood Bark Extract (polyphenol) and resorcinol resin formaldehyde mix - materials used were polyphenol western hemlock bark extract (HT-115) and resorcinol resin (Fire-X), mixed with paraformaldehyde. This system cured at room temperature and is water extendable (resorcinol resin itself precipitated when water was added).

   This resin combination was made and dried at 50 degrees Centigrade and higher. The resin cured but the bonding properties were so poor that the product fell apart, although it was taken in higher proportions than other binders.

Two compositions showed structural integrity and would not ignite under propane torch. These two compositions were studied further and results are given in Table 34.

Table 34: Compositions & Some Properties of Rice Hull Insulating Materials

Component/ Composition	RH-8	RH-12
Rice Hulls	100	100
MSC Prop. Binder	40	40
Fly Ash		200
Calcium Carbonate	200	
Water	150	150
Density (g/cm^3)	0.31	0.37
Compressive Strength (psi)	c.a. 100	c.a.100
Material Costs $/ft^3	1.02	1.02

These specimens were prepared as follows. Forty grams of MSC Proprietary Binder was blended (or hand mixed) with 150 ml water, 200 g filler added over a period of 2-3 minutes and then blended an extra minute. This mix was poured on the rice hulls and mixed until the hulls were wetted. The mixture was placed into metal mesh mold and dried at 50 degrees Centigrade or above for fast drying.

Composition RH-8 and RH-12 were subjected to NBS smoke test (using the American Instrument Co. Smoke Density Chamber). The results are summarized in Table 35.

Table 35: NBS Smoke Density Test Results

Sample	RH - 12	RH - 12	RH-8	RH - 8
Type of Test	Smoldering	Flaming	Smoldering	Flaming
Smoke Density	71	48	89	72
Time to Peak (Min)	18	20+	19	20
Time to Smoke D-16 (Min)	1.5	2.7	2.0	1.6
Size of Sample (in)	2.84x2.74 x1.18	2.90x2.90 x1.34	2.9x2.8 x1.06	2.82x2.75 x1.10
Weight retention after test (%)	57	60	49	47

Samples were conditioned at R.T. 50-55% R.H. for one week after being dried in the oven.

Test operating conditions were according to NBS method.

Rice hulls have some properties that make them good candidates for use as insulating materials.

1. Low apparent density.
2. Low price.
3. Rough surface that makes them easily bondable.
4. Contain 15-20% silica that lowers their flammability.
5. Abundant in many parts of the world.

The concept presented here includes three major components for the insulation material.

1. Rice Hulls - cheap and voluminous filler-reinforcement.
2. Inorganic Filler - Mainly introduced to make the part fire-proof. In case of inorganic powders that react with water and harden, they will act also as the binder.
3. Matrix Binder - organic or inorganic, is introduced in sufficient amounts to hold the other components together.

Any inorganic filler that will adequately disperse and not coagulate in the water-binder systems seems fit for this application, with some exceptions.

Following is a list of fillers that have already been used.

a. Magnesium Chloride - potentially a good fire proofer but because of its high hygroscopicity very hard to dry out and has a corrosive action on many common metals.

b. Magnesium Oxide - This material when used in proportion of 100/60 rice hull to MgO still shows considerable smoke evolution and maintains the flame for 1-2 seconds while larger amounts serve to make cost prohibitive.

c. Calcium Carbonate (Vicron) - a very inexpensive filler (2¢/lb) and which disperses very well. Seems to be a good candidate for fire-proofing filler (in proportion of 100/200 rice hulls/calcium carbonate). Experimental details later.

d. Fly Ash (Electrical Hopper) - is a very low cost filler, disperses very well and seems even better than calcium carbonate as a fire protector in proportions of 100/200 rice hulls/fly ash. Experimental details later. Establishment of another use for this material would help in easing disposal problems.

e. Casting Gypsum - is a cheap filler, disperses well and has an added pay-off by hardening through reaction with water to provide added strength to the insulating material. Also, the water incorporated in the crystal provides additional fire protection.

Composition RH-8 and RH-12 were subjected to a modified E-84 flame spread test. Test results are summarized in Table 36. Both smoke density and flame spread test results show very good fire resistance for these compositions, combined with low cost and light weight; these seem to have a good potential as insulation materials.

Additional binders, fire proofing agents, fillers and reinforcements were studied as potential components for fire-proof insulating materials. The emergence of some new compositions was combined with some concepts of potential use in housing and are discussed in the Product Section.

a. Binders

Vinyl Flat - (Western finishes) - This binder is a vinyl latex paint and was used in combination with rice hulls and fly ash. It proved to be a very weak binder and further work was discontinued.

Table 36: Flame Spread Test Results

Flame Front Length (in.)

Time (sec)	1/6" Asbestos Cement	Nom. 1 in. Red Oak	RH-8	RH-8	RH-12	RH-12
20	5	10	9	9	7	7
40	5	12	9	9	7	8
60	5	13	9	9	7	9
80	5	14	9	9	7	9
100	5	14	9	9	7	9
120	5	14	9	9	7	8
140	5	16	8	8	7	8
160	5	16	8	8	7	8
180	5	19	8	8	8	8
200	5	19	7	7	8	8
220	5	19	7	7	8	8
240	5	19	7	7	8	8
260	5	19	7	7	8	7
280	5	19	7	7	8	7
300	5	19	7	7	8	7
Avg. Maximum Length (in.)*	5	19	9	9	8	9
Flame Number**	0	14	4	4	3	4
Flame Spread Ratings	0	100	28.5	28.5	21.5	28.5
Flame Out Time	0	2-3	0	0	0	0
After Glow	0	4-5	0	0	0	0
Smoke Color	none	white	white	white	white	white
Smoke Quant.	none	medium	small	small	small	small
Smoke Odor		wood	wood	wood	wood	wood
Temp. of Sample (°C) ***		not measured	50°	50°	50°	50°

* Average maximum obtained from the three highest consecutive value recorded.

** Obtained by subtracting the maximum flame length of asbestos cement from the observed readings.

*** Temperature at the back of the specimens (across from burner) right after test.

Water Glass - (sodium silicate 41°Be) - was used in combination with rice hulls and fly ash (80g water glass to 100 rice hulls, 200g - fly ash). The material was oven dried, and upon removal from the mold, it fell apart. No further work is planned.

Proprietary Binder - A binder based on a MSC proprietary formulation was used successfully with combinations of rice hulls and inorganic fillers.

b. Fire-Proofing Agents

It is well known fact that materials like boric acid or sodium barate are excellent fire-proofing agents and are extensively used in the textile industry by just coating flammable textiles.

The use of these materials was tried in two approaches in the binder mix (as 5% solution), or presoaking rice hulls in a 10% solution and subsequently drying the hulls.

Unfortunately, these fire-proofing chemicals proved to be incompatible in our formulations.

c. Fillers - Insulants

Mineral Rock Wool - is an excellent insulant, inexpensive ($0.11/ lb.) and light weight. This was tried along with rice hulls as binder carriers, but the final formulations use glass fibers replacing the hulls.

Glass Wool - is a good insulant, light-weight with cost/weight slightly higher than mineral wool. It was tried with the same compositions as rock wool, but flame penetration of propane torch was much faster than for rock wool.

Vermiculite Perlite - These are expanded, light-weight minerals. When used in combination with water-based binder systems, they absorb both water and binder and the resulting parts were either weak or fell apart. It was obvious that increased proportions of binder and water would overcome this problem, but the end result would be a product both too heavy (entrapped water in expanded minerals), and too expensive for the considered applications.

Polystyrene Foam Beads - These are excellent, ultra light-weight fillers/insulants. Their geometry being spherical helps very much in mixing and dispensing of the mixtures in which they are incorporated. However, these beads make the products much more expensive and flammable; the best indication can be seen by faster burn-through when exposed to a propane torch.

d. Reinforcements

Glass Fibers - Chopped glass strands were studied with length ranging from 1/4" to 1".

As reinforcements for rice hull mixtures, the 1" long fibers gave best results combined with satisfactory processing; 1/4" fibers were found more satisfactory with mineral rock wool, mainly because of mixing considerations. Two different fiber sizing were also evaluated, silane finish (which is normally used with organic resins) and oil-starch finish. In all cases where there was a water-based formulation, the fibers sized with oil-starch out-performed the others in the final strength and integrity of the products. The oil-starch finished fibers dispersed easily and adapted themselves to the mixture. Conversely, the silane finished fibers behaved as stiff bundles, were ineffectively dispersed and allowed less compaction of the products which results in lowered strength.

Cotton Waste - This material is inexpensive and fiber-like and was introduced as possible reinforcement and to promote nailability. There was no proper equipment available to defibrillate the bundles, so the use of cotton waste as supplied posed mixing problems and non-uniform dispersion of fibers; however, reinforcing and improved nailability were obvious. There is, however, another reason that rules out the use of cotton waste with water-based formulation. Shortly after fabrication, there was development of mold(fungus) on the cotton which would require appropriate preventive treatment if considered for use.

At this period of the study, a review was made of all the formulations. It was determined that RH-8, RH-21, RH-31 and RH-46 offered the greatest potential. These are summarized in Table 37. Formulation RH-31 was developed as a structural fire wall insulation. A series of tests were conducted on the material with thickness of 0.5, 0.83 and 1.09 inches. These tests were for the purpose of determining char depth, burn-through and back temperature.

Samples were placed vertically in 4" x 4" gypsum board which had a center 2" x 2" hole cut out. A thermocouple was fastened to the center at the back by means of a steel strip.

A propane torch with 3/4" nozzle was placed 5" away from sample surface; gas pressure was about 27 psi.

Temperature on front surface was adjusted to 1600 degrees Farenheit, with a thermocouple used to check temperature.

The insulation properties of RH-31 versus gypsum board are demonstrated in Figure 13. The insulation effect is not linear with thickness because the properties of developed char are different from the non-burned material. The most interesting phenomenon is the 100 degrees Farenheit drop in temperature after the peak is reached. This drop is followed by a stabilized temperature. This again is attributed to the char which becomes a super insulator. The peak was not reached for the one inch samples as 2 hours is considered adequate fire protection.

Figure 14 further emphasizes the importance of having at least 1" thick insulation for long exposure periods; after 60 minutes 0.75 inch are charred and the curve showed that any further charring would likely advance very slowly.

Rice hulls syntactic foam are not intended to be exposed to outside conditions or high humidity. However, it was of interest what effect adverse conditions will have on these materials.

TABLE 37: RICE HULLS SYNTACTIC FOAMS

Material No.		RH-8	RH-12	RH-21	RH-31	RH-46
Composition (Parts by weight)	Rice hulls	100	100	100	100	100
	1" Glass Fibers			5	5	5
	Proprietary Binder	40	40	40	40	40
	Calcium Carbonate	200				
	Casting Plaster				300	400
	Fly Ash		200	200		
	Water	150	150	130	200	260
Density (g/cm^3)		0.31	0.37	0.35	0.69	0.74
Nail Withrawal (lbs)				18	43	45 - 70
Compressive (PSI) Strength		100	100	350	700	1200
Flame Spread		28	24	24	12	7
Smoke Density		72	48	48	15	10
Material Cost ($/ft^3)		1.02	1.00	1.02	1.50	1.60

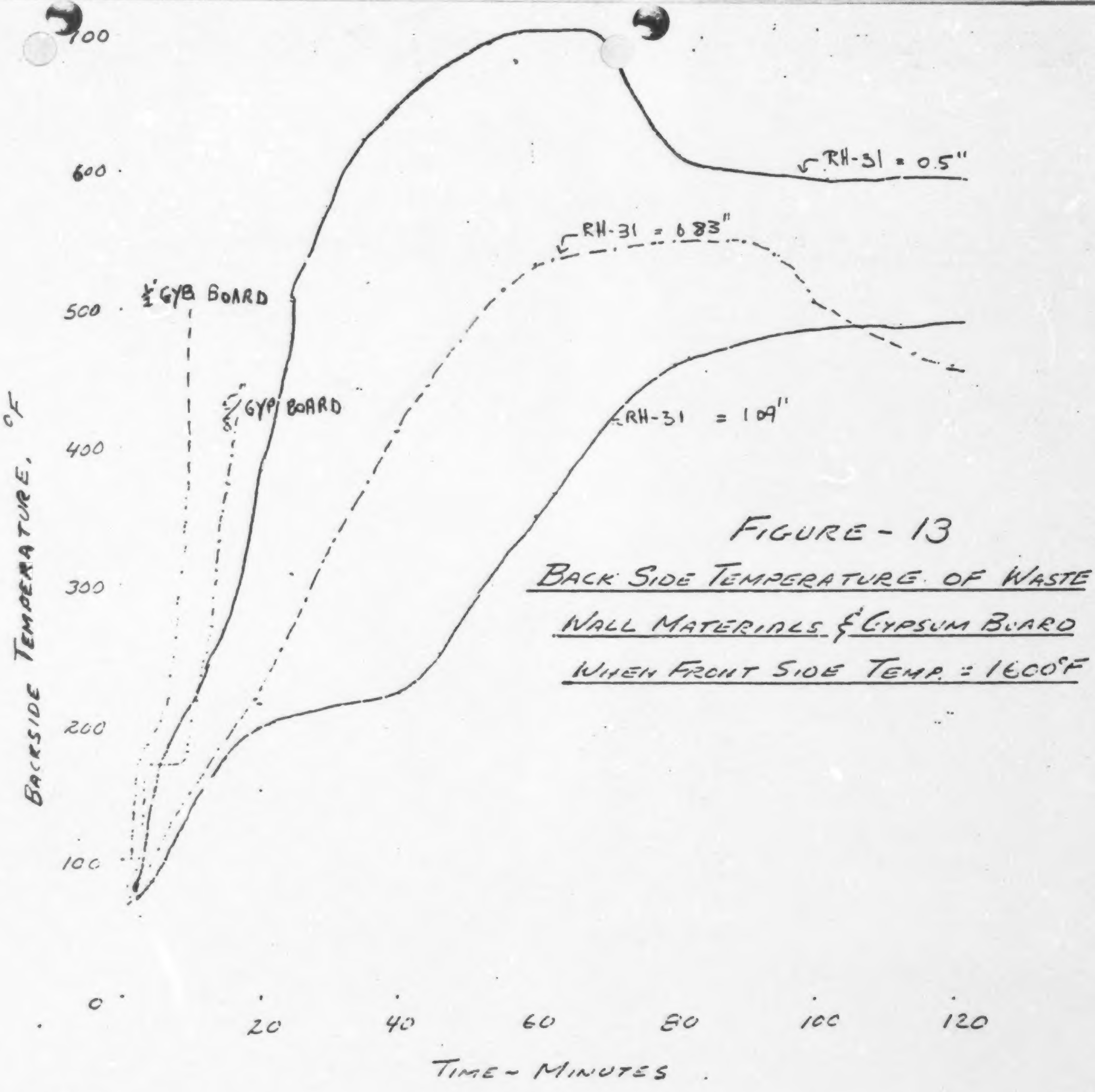

FIGURE – 13

BACK SIDE TEMPERATURE OF WASTE WALL MATERIALS & GYPSUM BOARD WHEN FRONT SIDE TEMP. = 1600°F

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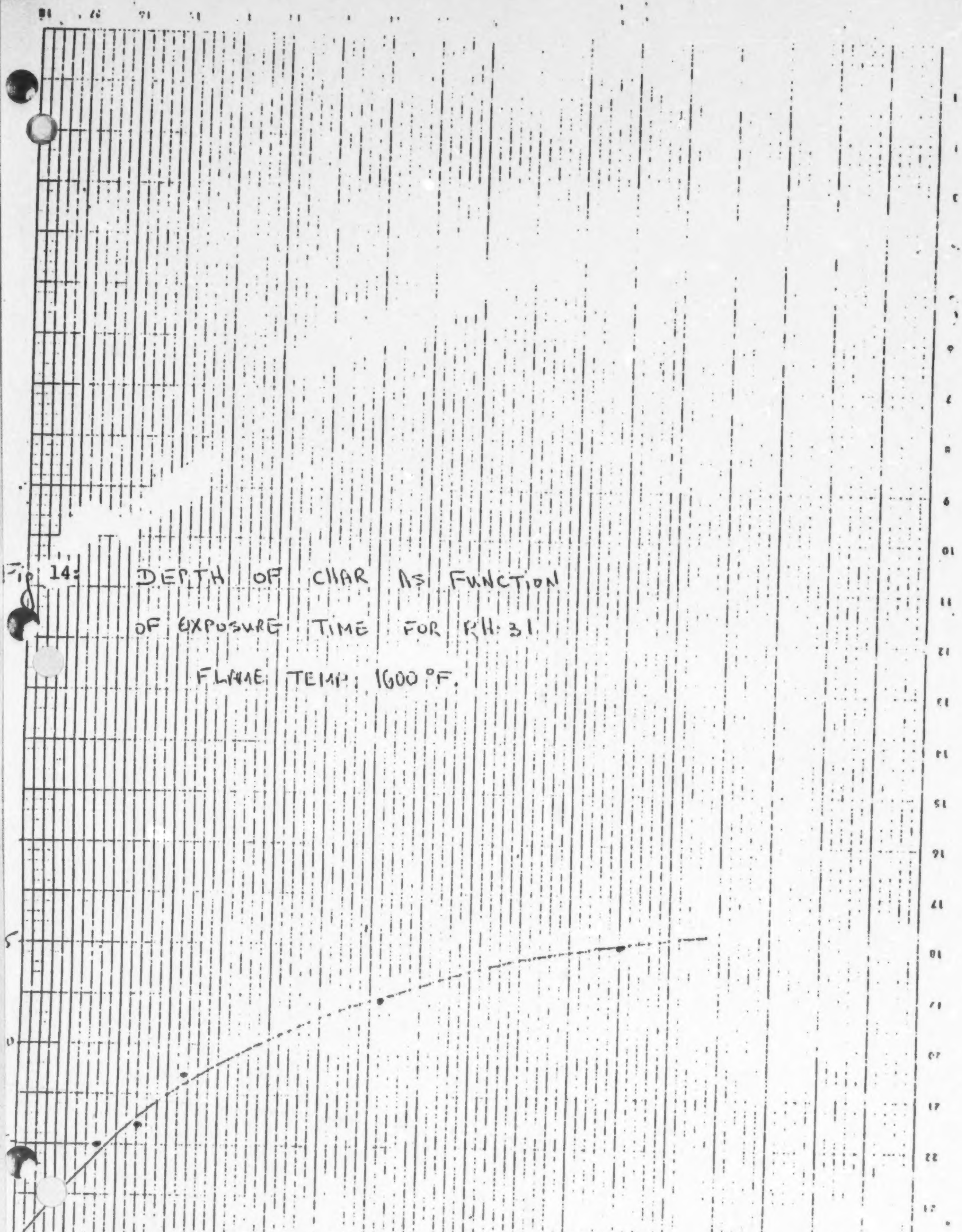


Fig. 14: DEPTH OF CHAR AS FUNCTION OF EXPOSURE TIME FOR RH 31 FLAME TEMP: 1600°F.

The materials were soaked in water up to 7 days. Weight, compression strength and nail pull changes were checked. Accelerated weathering up to 400 hours was also carried out. Construction of the weatherometer chamber does not allow samples thicker than 1/2", so only weight changes could be measured. Water soak data (from Table 38) showed a higher density material which means more plaster absorbed less water. RH-21 which included just fly ash absorbed the highest amount of water.

Fly ash-containing materials drastically lost their compression strength and nail pull resistance. Plaster-containing materials lost strength and suffered from lowered nail pull resistance but to a lesser extent. No significant difference was noted due to increased amount of plaster. Weatherometer data showed weight loss, which indicated leaching out of either fly ash or casting plaster. After drying, the samples were firm and not warped.

The original formulations utilized "20-minute" casting plaster. The scale-up of this process, called for mixing in a cement mixer and lay-up in a large mold. This scale-up increased the work period, and "20-minute" casting plaster caused hardening before the process was complete.

A study was carried out to retard the reactivity of casting plaster. The main problem encountered was reduced compressive strength.

Table 40 includes a summary of various experiments to retard casting plaster and the effect on hardening time and compressive strength.

The attempt to retard by adding more water had an opposite effect - hardening time was shortened along with reduction in compressive strength.

Red Top Retarder (U.S. Gypsum) incorporated between 0.2-5.0 parts by weight, effectively increased hardening time, but compressive strength was reduced too much, even with as little as 0.2 parts. The same effects were noted by replacing 15% of 20-minute casting plaster with gypsum plaster.

Finally, "90-minute" casting plaster was used and the results are comparable with those of neat "20-minute" casting plaster. It should be noted that the optimal amount of water is 270 parts by weight, higher amounts causing settling of the casting plaster.

SUMMARY

There are a variety of inorganic matrix laminates and foams of waste materials that can be used competitively in the construction industry. The design properties for the laminate are presented in Figure 11.

It was noted in the above studies that fungus (mold) growth can occur on rice hull syntactic foams. This required a study for finding proper and effective fungicides to prevent mold growth. This might result from residual humidity in the product or penetration of water when functioning as a wall panel.

Table 38: Water Soak and Accelerated Weathering Data

Test \ Material	RH-21	RH-31	RH-46
Water Soak			
Weight pick up (%)			
2 hr. soak	49	36	29
24 hr. soak	51	37	31
168 hr. soak	52	46	36
Compressive St. (psi)			
Control	350	700	1200
2 hr. soak	96	390	390
24 hr. soak	38	340	370
168 hr. soak	21	250	360
Nail pull (lb.)			
Control	18	43	45-70
2 hr. soak	6	19	16
24 hr. soak	4	27	25
168 hr. soak	3	22	30
Weatherometer			
Weight Loss (%)			
200 hr.	3	9	12
400 hr.	6	21	19

Products of two manufacturers were tested; Vanderbilt and Buckman laboratories. However, only Buckman laboratories agreed to innoculate and extensively test the prepared samples. The following is a summary from tests carried out by Buckman laboratories (Table 39).

The submitted samples were innoculated with the following fungi:

Pencillium Roquefortii
Aspergillus Niger
Chaetomium Globosum
Aerobacter Nerogenes

It was discovered that untreated samples had profuse growth of Aspergillus spp. which originated here in California.

The tests resulted in a recommendation to use 0.6 to 1.0 part by weight (with 100 pbw rice hulls) of Busan 30-I.

Buckman laboratories have extensively tested cellulose containing materials treated with Busan 31 in humid conditions and soil environment. This fungicide was found very satisfactory and is used for treating wood for construction industry.

Busan 30-I contains:

Active Ingredients - 2-(Thiocyanomethylthio)
benzothiazole.......30%

Inert Ingredients...70%

The foam characteristics are summarized in Table 37, Figure 13 and Figure 14. From these materials a vast variety of products can be developed.

Table 39- Fungicide Treatment of Rice Hull Syntactic Foam (RH-46)

Sample	Treatment	A. Niger Growth	P. Roquefortii	C. Globosum	A. Aerogenes
RH-46-T	untreated-control	profuse	profuse	profuse	none
RH-46-T-1	Busan 30 (0.3 pbw)*	profuse	none	none	none
RH-46-T-2	Busan 30 (0.6 pbw)	slight	none	none	none
RH-46-T-3	Busan 30 (1.0 pbw)	none	none	none	none
RH-46-E	Busan 52 (0.5 pbw)	profuse	slight	none	none
RH-46-F	Busan 52 (1.0 pbw)	profuse	profuse	none	none
RH-46-G	Busan 52 (2.0 pbw)	profuse	none	none	none

* PBW relative to 100 pbw rice hulls.

Table 40: Retardation Experiments of Rice Hulls/Casting Plaster Flooring Formulations

Mix / Formula	RH-46	RH-46Q	RH-46-R	RH-46-S	RH-56	RH-46-L	RH-46-K	RH-46-J	RH-46-P	RH-46-N	RH-46-M	RH-60-B	RH-60-C	RH-60
Rice Hulls	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1" Glass Fibers 636AB	5	5	5	5	5	5	5	5	5	5	5	5	5	5
MSC Proprietary Binder	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Water	260	280	300	320	260	260	260	260	260	260	260	240	260	270
Casting Plaster "20 min"	400	400	400	400	340	400	400	400	400	400	400			
Casting Plaster "90 min"												400	400	400
Gypsum Plaster					60									
Red Top Retarder(1)						5.0	3.0	1.0	0.8	0.4	0.2			
Hardening Time (min)	20	14	11	9	130	over-night	over-night	160	205	50	35	90	80	70
Compression(2) Strength (R.T cure after 8 days) (PSI)	925				600	550	560	600						
Compression Strength R.T. cure + 60°C oven cure, 6 hour (PSI)	1150	770	630	540	800	820	770	840	680	650	670	950	1070	1160

(1) Red Top Retarder, product of U.S. Gypsum.

(2) All Compressive tests were carried out by pressing a 1" steel cube, on a 3"x6" (2" high)

Note: All mixtures prepared and R.T. cured at 74°F

PRODUCTS ORGANIC MATERIALS

There are a variety of products conceivable from the organic materials developed here. The ones evaluated in this program with the most promise are as follows:

1. Structural Board
2. Replacement for Sheet Rock
3. Lumber Substitute
4. Fire Doors

Each of these are discussed in detail below.

STRUCTURAL BOARD

This is a direct substitute for commercial grade particle board (chip board). The formulations to be considered are presented in Table 41. These materials can be produced in various densities and strengths as can commercial particle board. However, this program restricted its activity to the maximum strength and density. Lower levels would be achieved in the productization phase.

The 55 pound per cubic foot density,commercial grade particle board was used as the competitive standard. The characteristics of this standard are presented in Table 42.

Table 43 compares flame spread and smoke generation with the standard. The lower the number, the more acceptable the product is for safety. As can be seen, rice hulls are far superior to commercial particle board. Peanut shells are very close to the rice hulls in performance also.

Table 44 presents a comparison of the modulus of rupture for various organic materials and commercial particle board. All materials are acceptable or superior to particle board. The corn cob product may be questionable for high load requirements.

TABLE 41: SELECTED FORMULATIONS FOR ORGANIC MATERIALS

Material No.		YT-26	YT-58-C	YT-61-C	YT-63-C	YT-64-C	YT-33	YT-126
Composite Material		Rice Hulls	Pine	Alder	Redwood	Ash	Corn-cobs/ Rice Hulls	Peanut Shells
Acid		p-toluene Sulfonic	Phosphoric Acid	Phosphoric Acid	Phosphoric Acid	Phosphoric Acid	Hydrocholoric Acid	Phosphoric Acid
Molding -	Temp °C	150	150	150	150	150	150	170
2"	Time (min)	5	3	5	3	3	5	15
Thick	Pressure (PSI)	500	500	500	500	500	500	500
Density (g/cm^3)		1.08	1.06	1.03	1.11	1.02	0.95	1.00
Modulus of Rupture (PSI)		1322	2297	2148	3236	3188	1034	2400
Straight Nail Pull (lb)		13	39	-	-	67	-	-
Straight Screw Pull (lb)		130	252	-	-	378	-	-
Flame Spread		58	95	-	-	123	-	-
Smoke Number		51	315	-	-	198	-	200
Water Soak -	% weight gain	27	23	39	54	29	-	-
days	% thickness gain	13	12	21	11	9	-	15
Hardness	Before Test	64	75	64	71	80	-	80
	After Test	55	40	36	63	58	-	60
Weather-o-meter Water- 350 hrs.	% weight loss	17	18	20	17	30	-	-
	% thickness gain	27	4	25	3	4	-	-
Hardness	Before Test	63	79	65	75	79	-	-
	After Test	35	41	22	58	27	-	-

TABLE 42

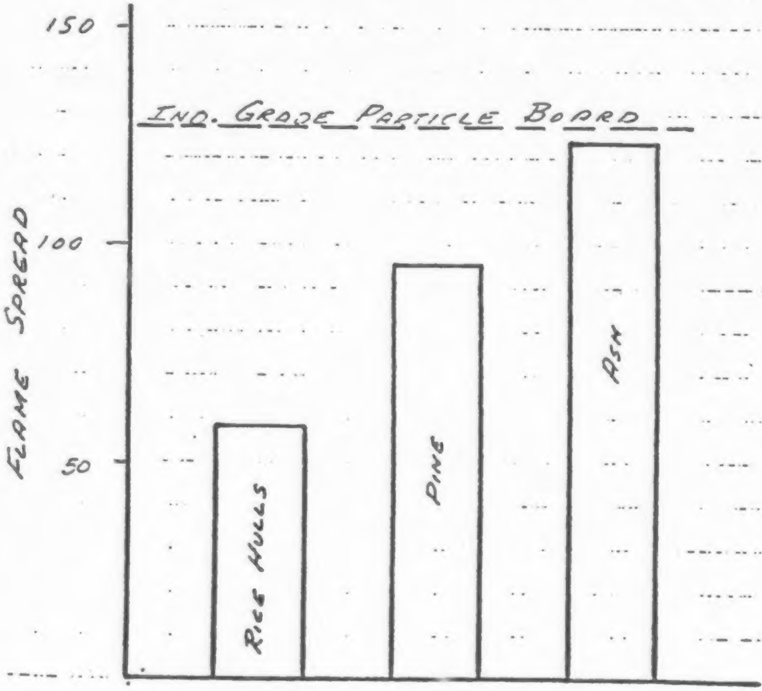
55 lb/ft^3 COMMERCIAL GRADE PARTICLE BOARD

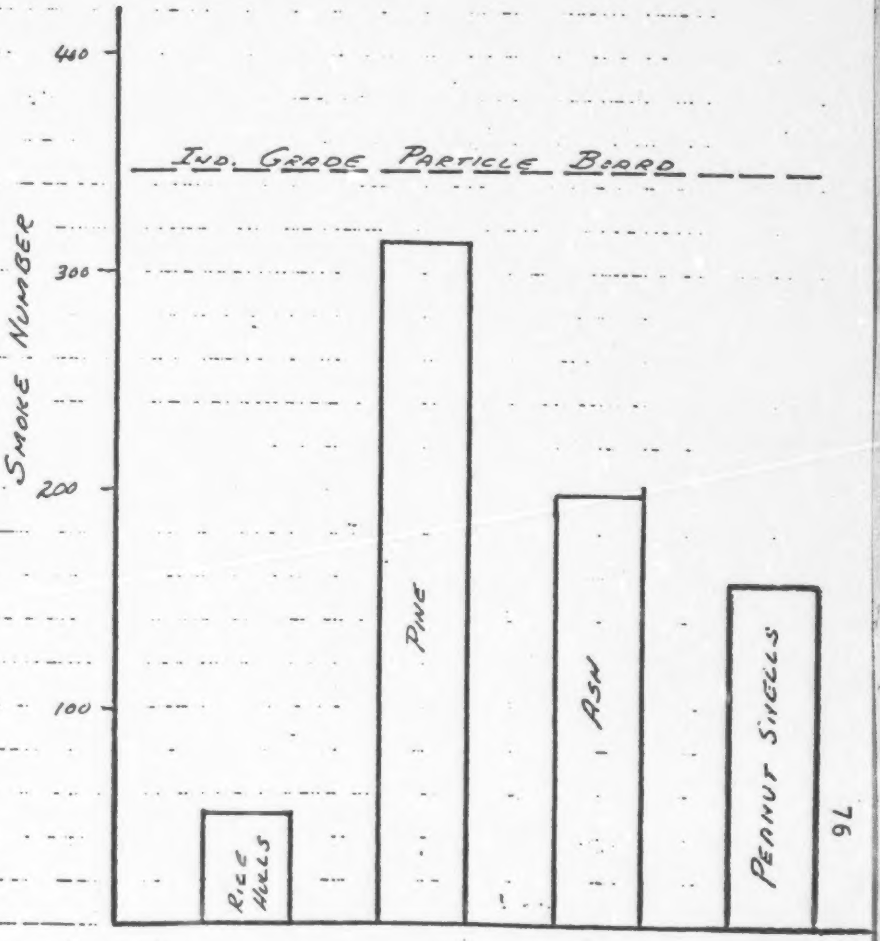
Modulus of Rupture	1500 psi
Straight Nail Pull	56 lbs
Straight Screw Pull	296 lbs
Flame Spread	127
Smoke Number	345
Water Soak (7 days): Wt. gain	64%
: Thickness gain	22%
Hardness - Shore "D": Before Soak	70
After Soak	50
Weatherometer 350 hrs: Wt Loss	14%
Thickness gain	22%
Hardness - Shore "D" after weathering	50

TABL - 43

ORGANIC COMPOSITE

FLAME & SMOKE CHARACTERISTICS





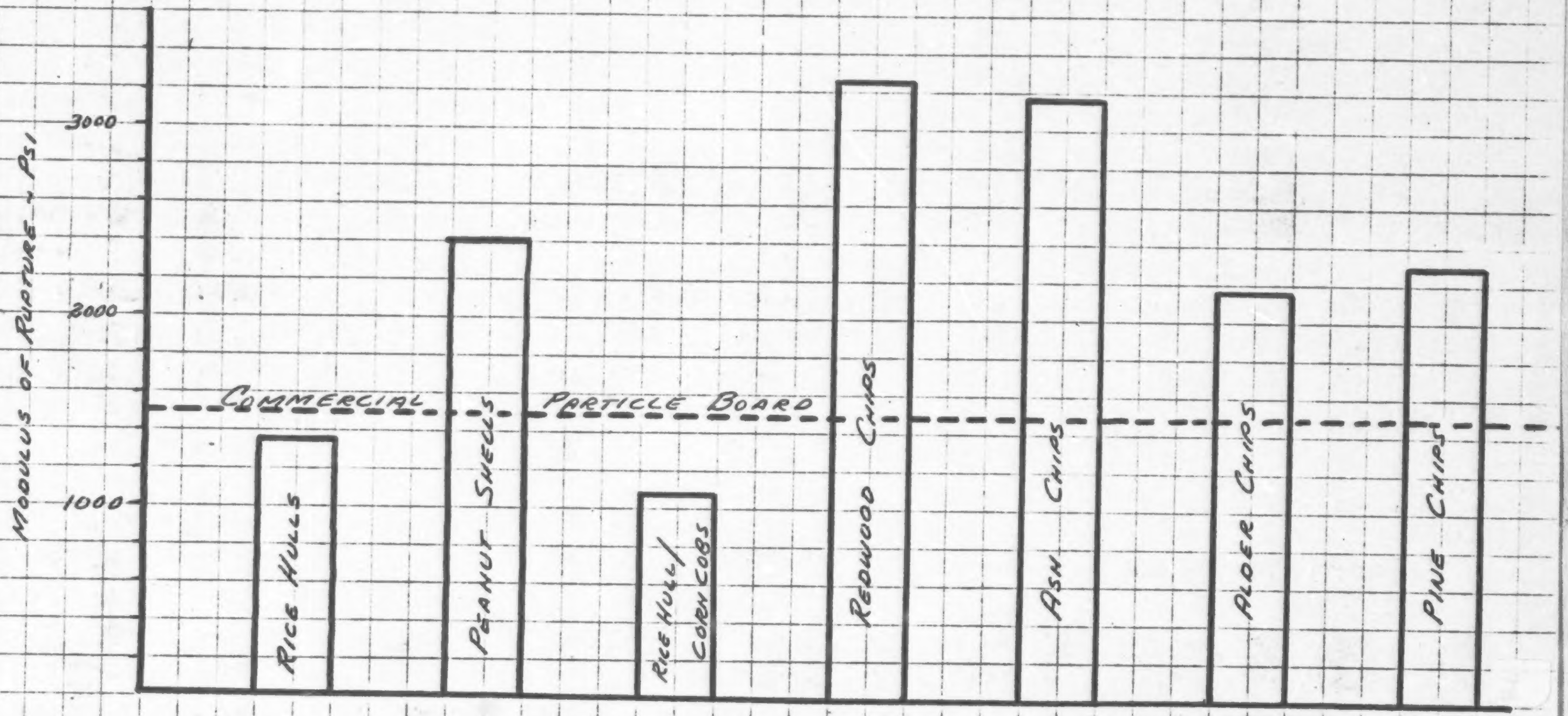
The material cost for the various waste material panels are developed in Appendix B. The costs assume that the material is converted into the product at the waste material source. This is being done in the particle board industry. However, MSC has developed a process by which the waste is acid treated, heated and dried into low density billets. This would reduce the typical shipping cost from $.014/lb to $0.005/lb. The billet-producing equipment is inexpensive compared to the cost of the presses or drier required to convert the billet into a structural panel or shape.

Table 45 presents a comparison of the various waste material cost per cubic foot with that of equivalent strenght commercial particle board. Labor and equipment amortization costs are equivalent and therefore can be neglected. As can be seen, waste products can produce an equivalent and, in the case of fire and smoke, superior products from 35% to 68% of the cost of commercial particle board. If a 500 mile radius for transportation of raw materials was added to this cost, the cost would increase 50% to 70%. However, the same factor holds true for commercial particle board.

Another feature of the rice hulls and peanut shells is that the thermal conductance and behavior under fire is much like sheet rock. The behavior of sheet rock, commercial particle board, rice hull board, and peanut shell board under the E-119 fire test requirement are presented in Figures 15, 16, 17 and 18. All are basically 20 minute rated materials. Because of the difficulties in controlling the fire, the failure time has to be related to the area under the curve of the measured heat. Based on such an adjustment, the sheet rock would be rated for 24 minutes, the commercial particle board for a little less than 20 minutes, the rice hull panel for 27 minutes and the peanut shell panel for a little less than 20 minutes. The particle board surface burns readily. The peanut shell

TABLE 44

MODULUS OF RUPTURE FOR VARIOUS ORGANIC MATERIALS



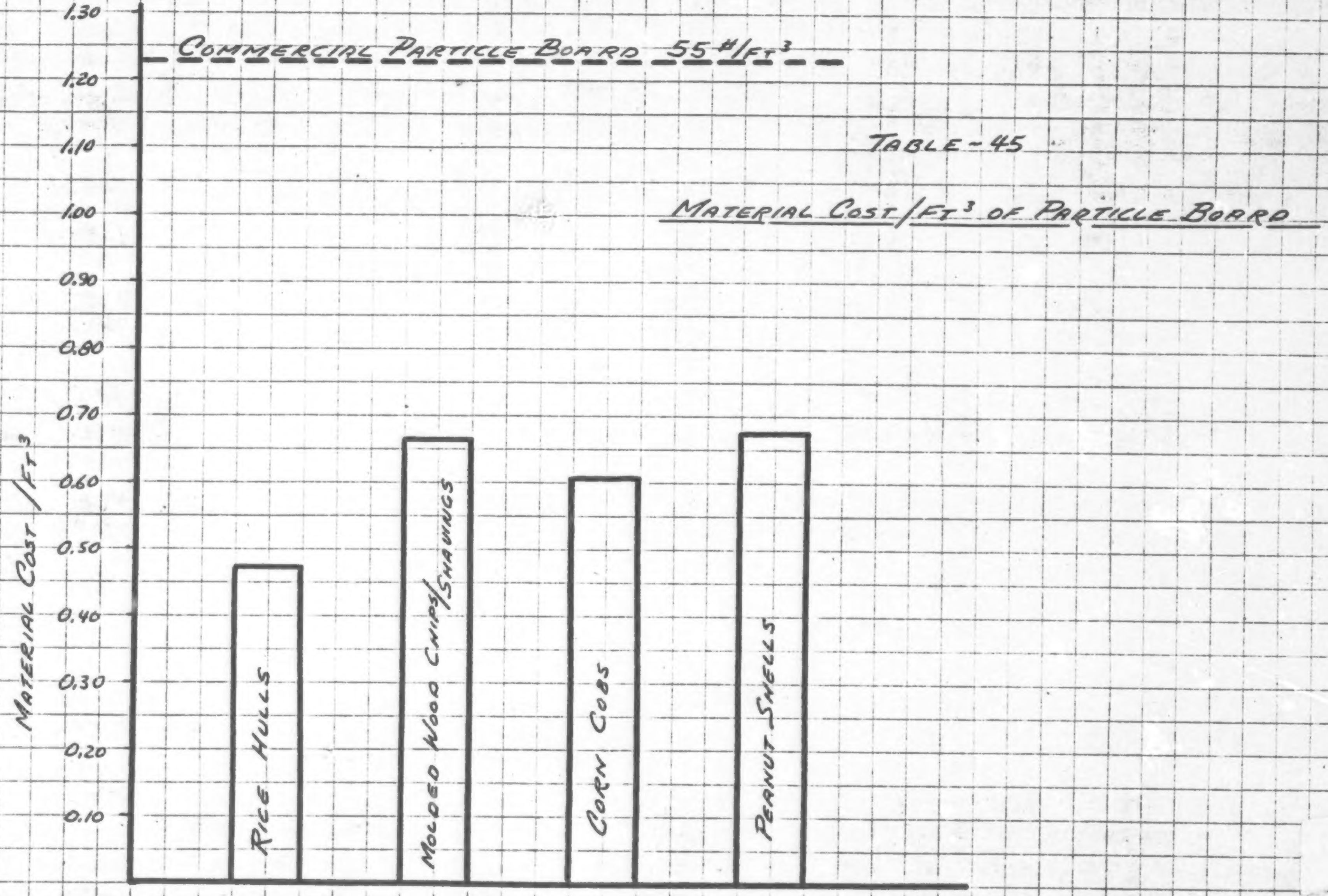


TABLE - 45

MATERIAL COST / FT^3 OF PARTICLE BOARD unexposed surface began to burn at the 15 minute period. The rice hull panel does not smoke or burn.

It can be summarized from these tests that both the rice hull and peanut shell panels are superior to commercial particle board in a fire. It can also be concluded that the rice hull panels are superior to the sheet rock panel in a fire. The rice hull panel was intact and handleable, with care, after the fire where the sheet rock panel cracked and fell apart.

Appendix B presents a cost analysis of the organic particle board. These costs can be utilized to determine the cost for a 1/2 inch 4ft x 8ft panel. Densities of 60 lb/ft^3 plus as tested will be compared with commercial 55 lb/ft^3 particle board.

	Rice Hulls	Peanut Shells	Wood Chips	Commercial Particle Bd.
(1) Material Cost	0.632	0.898	0.881	1.681
(2) Cost to Mfg (1.67)(1)	1.055	1.501	1.471	2.807
(3) Cost to Retailer (1.25)(2)	1.318	1.876	1.838	3.509
(4) Cost at Retail (1.54)(3)	2.031	2.889	2.832	5.402

Based on this analysis the retail price of the waste process particle board would be 38% to 53% of that of commercial particle board. Figure 19 presents a summary of material costs for various thicknesses of 4' x 8' board.

Two commercial processes now in use are presented in Figure 20. The MSC process will utilize much of the same equipment and is shown in Figure 21. The rice hulls or peanut shells will be fed into a storage area from which measured amounts will be transported to the resin wash. From the resin wash, the material will go to a wet preformer. The preformed billets will then be passed through a dryer to remove excess water. The dry billets are then pressed, post treated and trimmed. Table 46 presents a summary of estimated equipment costs for a plant to produce 50 to 60 million square feet of panel

FIGURE ~ 15

FIRE TEST OF 1/2 INCH SHEET ROCK

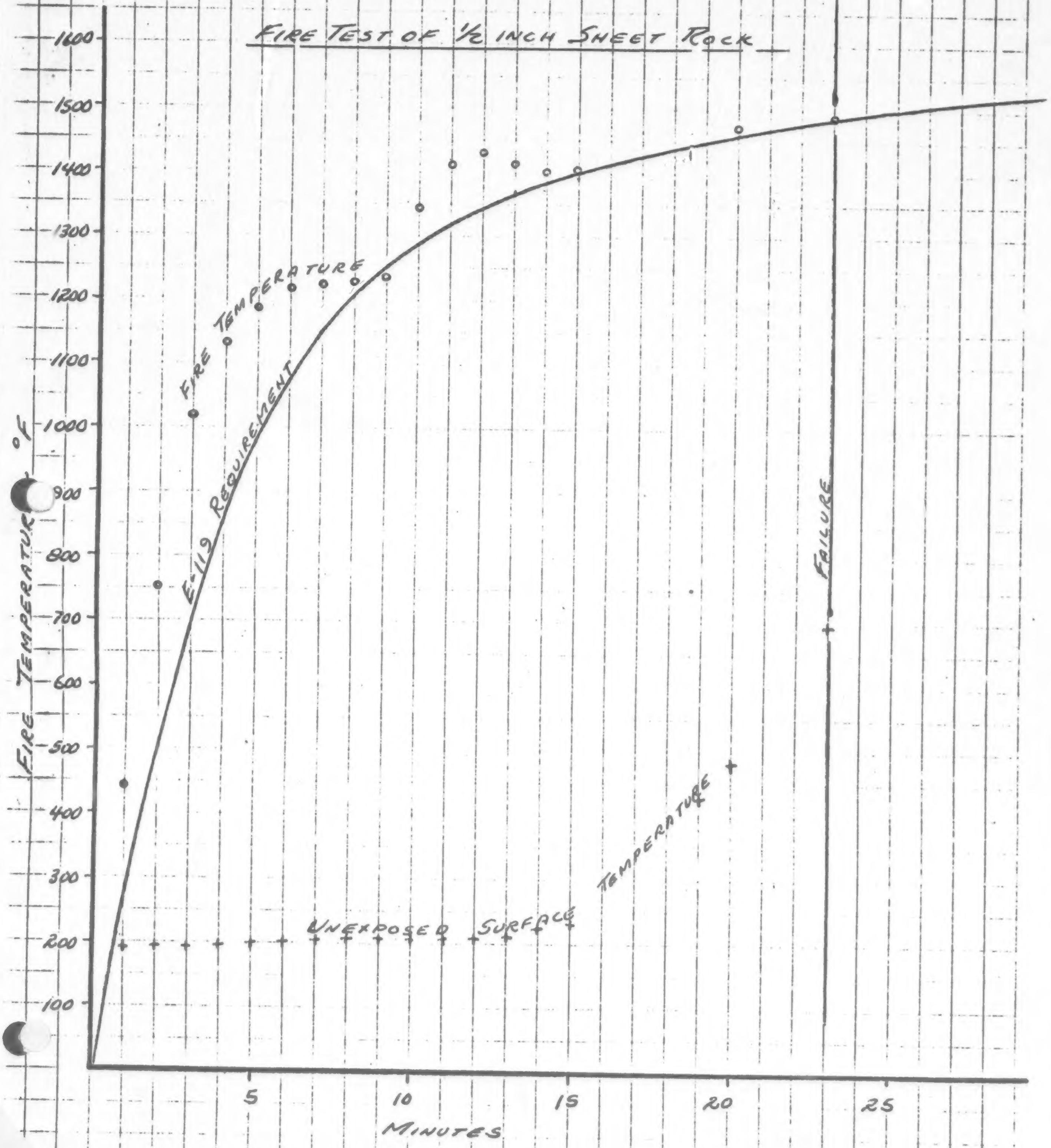


FIGURE - 16

FIRE TEST ½ INCH COMMERCIAL PARTICLE BOARD

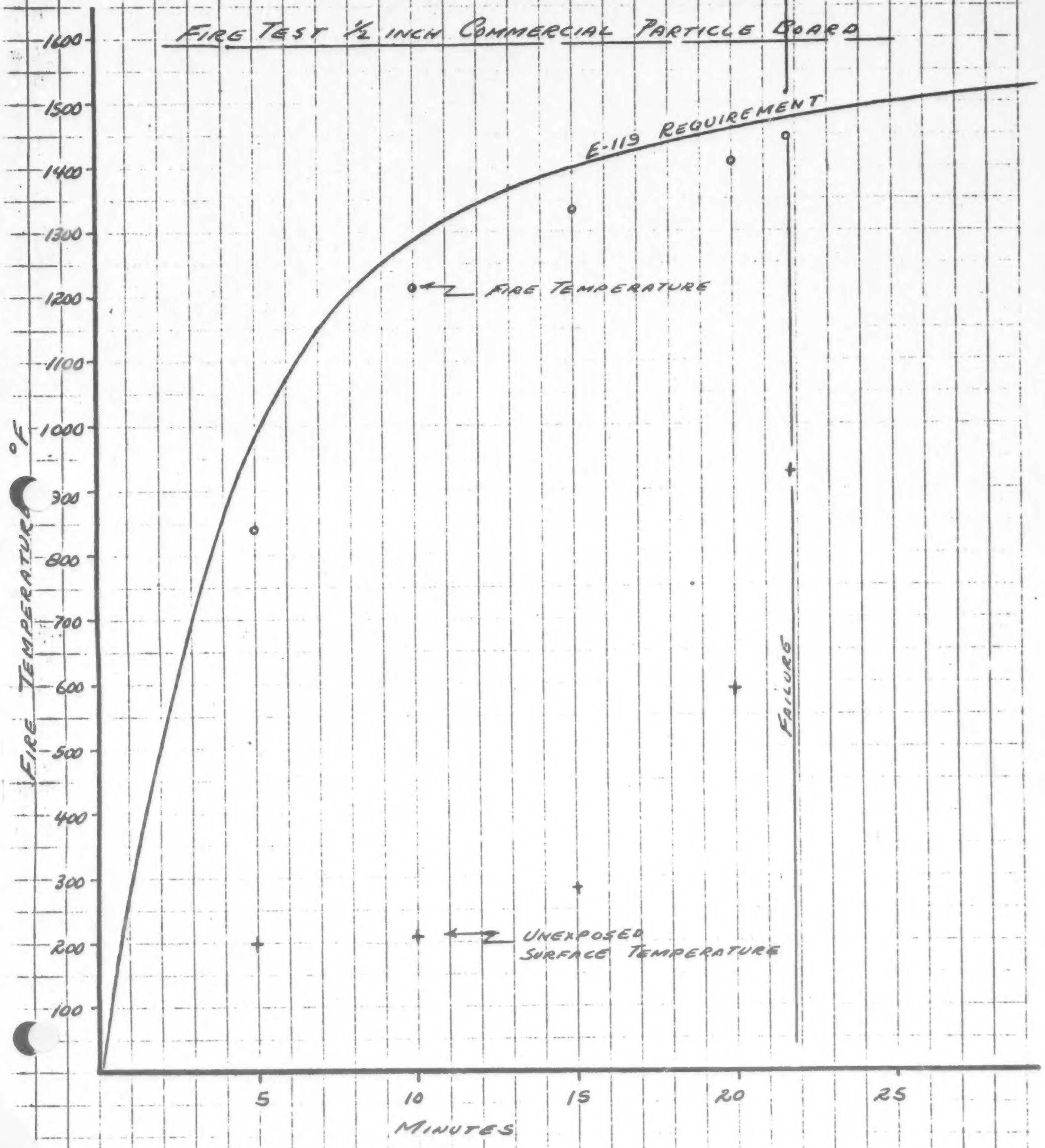


FIGURE - 17

FIRE TEST OF 1/2 INCH RICE HULL BOARD

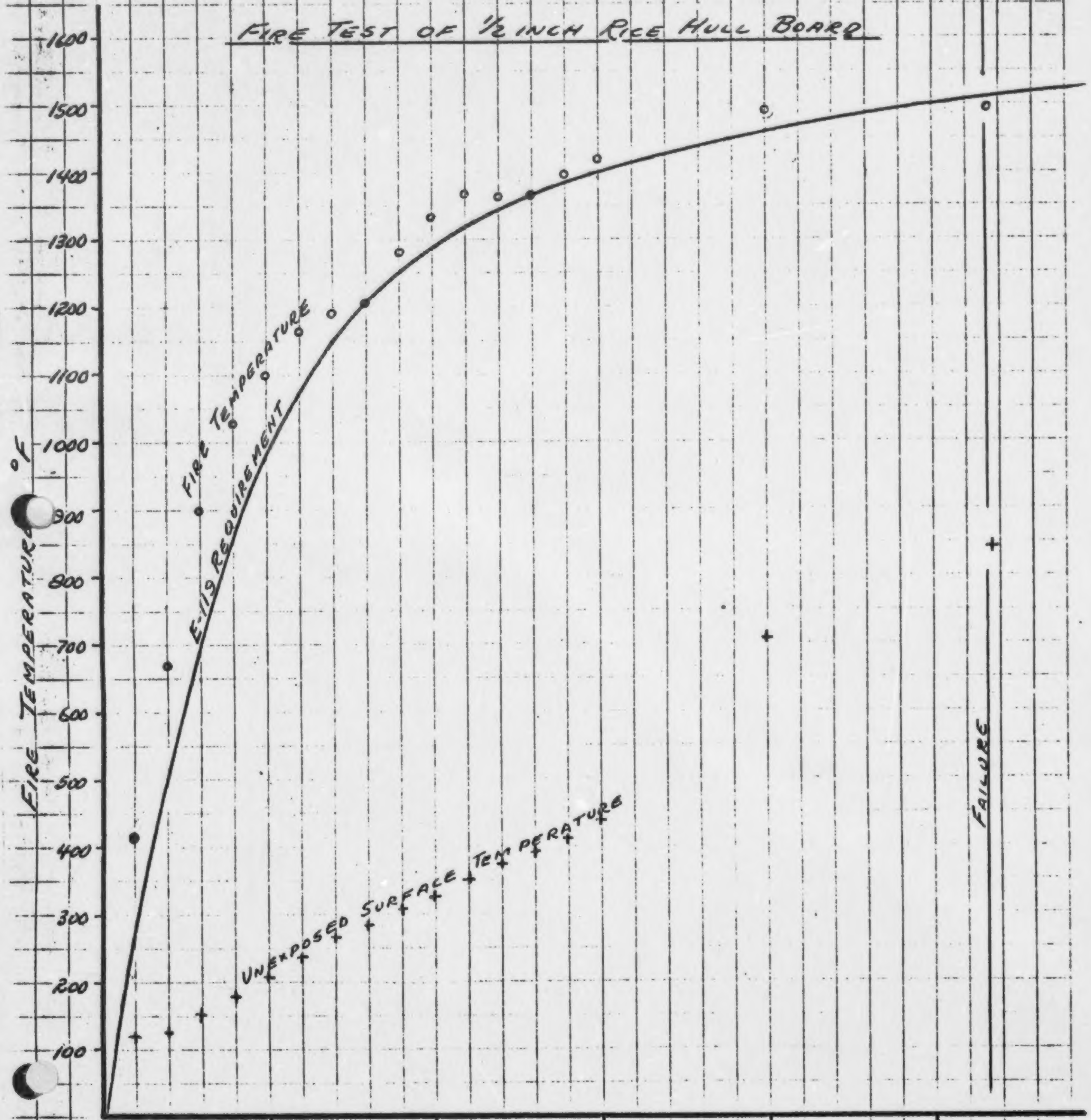
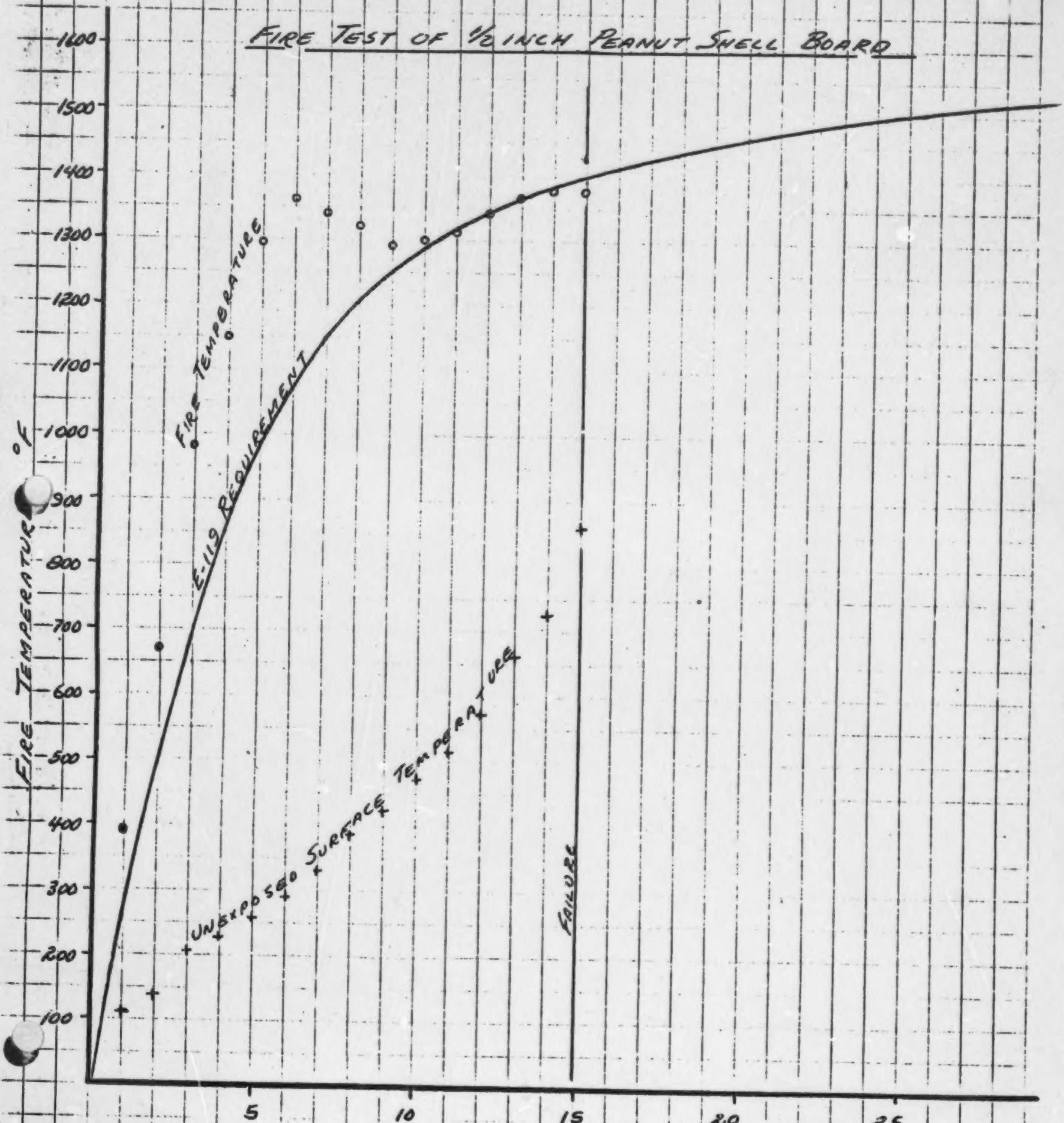


FIGURE- 18

FIRE TEST OF 1/2 INCH PEANUT SHELL BOARD



a year. As can be seen, the waste process for particle board would cost about 78% of that of a conventional plant.

If it is assumed that the inflation rate on equipment costs have been 3 since 1967 and the other costs 2, then the facility costs would be approximately $9,000,000 (See Appendix B). The following analysis can then be made for this process.

1. Assume the plant cost is $9 million.
2. Material cost is .007/lb (rice hulls), .011/lb(peanut shells), .010/lb (wood chips).
3. Assume sales to retailer are .048/lb (commercial particle board).
4. Generated differences are

   Rice Hulls = .041/lb

   Peanut Shells =.037/lb, and

   Wood Chips = .038/lb.

   This assumes the plant is in the waste producing area. Transportation costs are in the sales to retailer.
5. The fixed operational costs are as follows

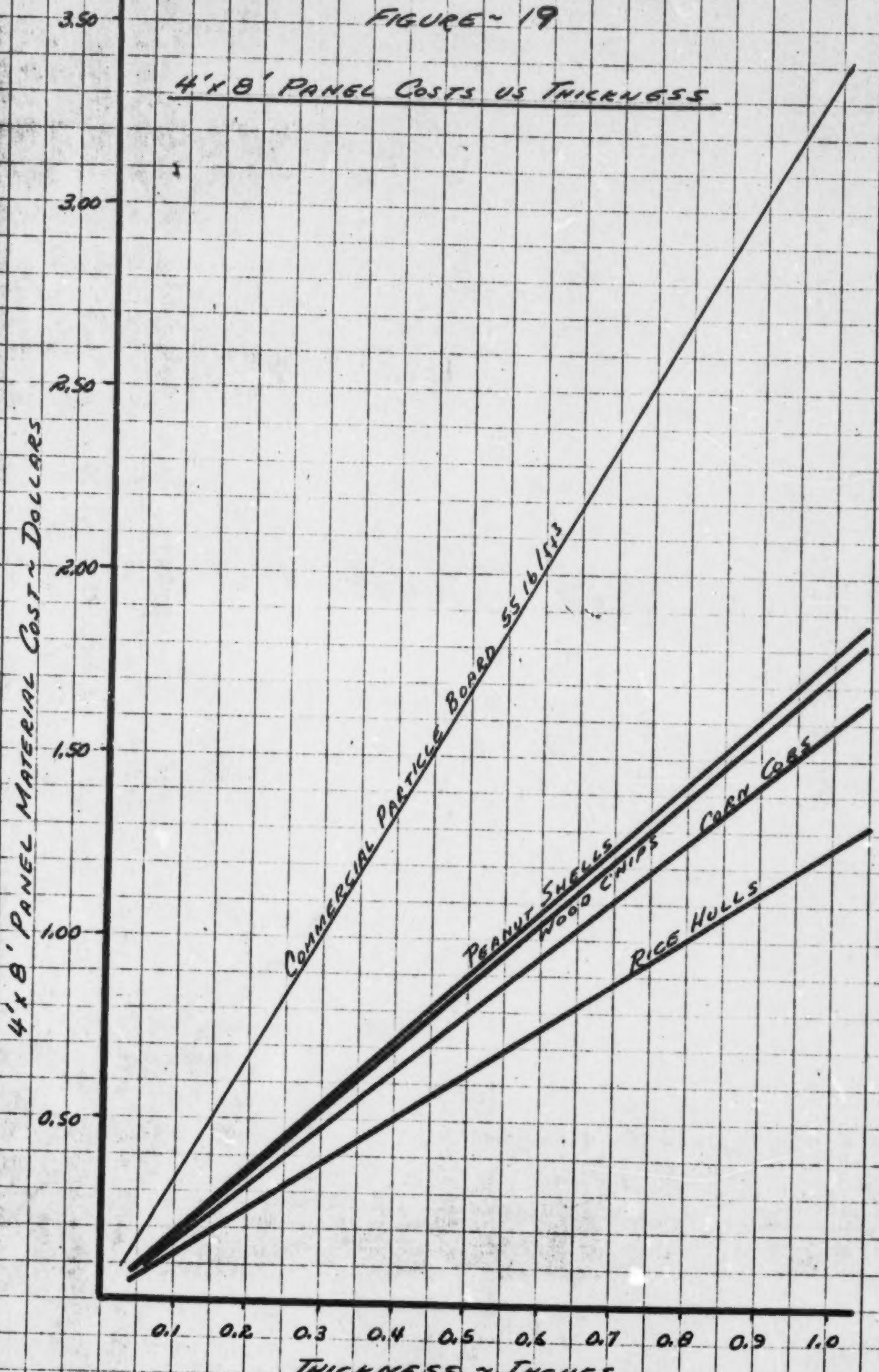
Labor	$561,000 per year
Maintenance & Operating Supplies	275,000 per year
Indirect Costs	429,000 per year
Depreciation	900,000 per year
	2,165,000 per year

   Per day costs = $8,326 per day
6. There is an additional 7% of material cost added to all cost of production.
7. The break even production rate would then be

   Rice hulls: $$\frac{\$8{,}326/\text{day}}{.041/\text{lb} - (.007\text{lb})(.07\ \text{cost/lb})} = 205{,}580\ \text{lbs/day}$$

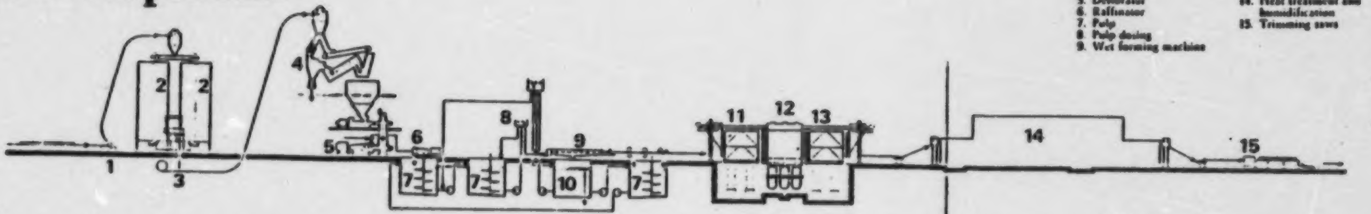
FIGURE ~ 19

4'x 8' PANEL COSTS VS THICKNESS



Reproduced from best available copy.

The wet process

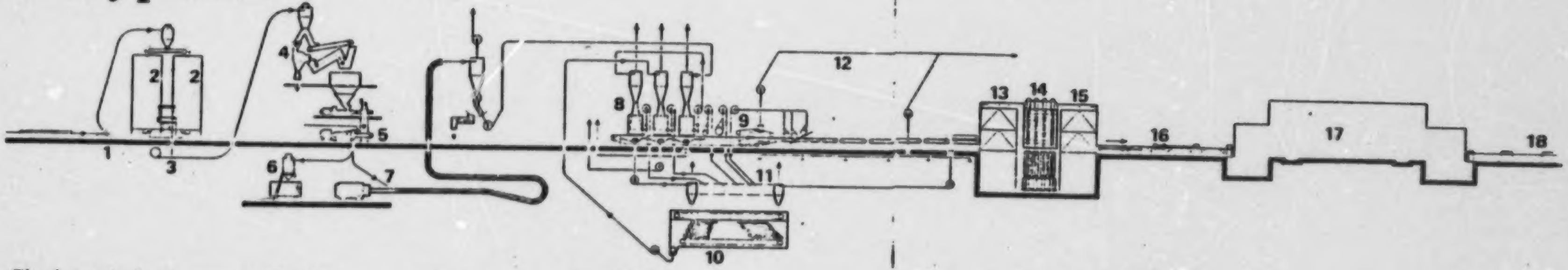

1
2
2
3
4
5
6
7
7
8
9
10
7
11
12
13
14
15
1. Chipper
2. Chip silos
3. Chip screen and rechipper
4. Chip washer
5. Defibrator
6. Raffinator
7. Pulp
8. Pulp dosing
9. Wet forming machine
10. White water bin
11. Loading hoist
12. Hot press
13. Unloading hoist
14. Heat treatment and humidification
15. Trimming saws

The wet process is the most firmly established method for the manufacture of hard, semi-hard and insulation board products.
It has been in use for more than 40 years, in the course of which considerable practical experience has been gained.

The experience, the simplicity of the method and the constant improvement of machinery, enables preset product capacity and quality to be reached easily and quickly.

The wet method is used for production lines with daily fiberboard outputs ranging from 20 to 250 tons, in thicknesses varying from 2 mm for hard and to 25 mm for insulation board.

The dry process


1
2
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11
12
13
14
15
16
17
18
1. Chipper
2. Chip silos
3. Chip screen and rechipper
4. Chip washer
5. Defibrator
6. Start fiber cyclone
7. Dryer
8. Forming station
9. Precompressor
10. Fiber bin
11. Cyclones
12. Dust collector
13. Loading hoist
14. Hot press
15. Unloading hoist
16. Presaw
17. Conditioning
18. Trimming saws

The dry method is characterized by high production output, implying a lower production cost per ton of board.

Board characteristics and thicknesses can be varied over a wide range and the production output is not appreciably affected when thicker board is produced.

FIGURE 20

COMMERCIAL PARTICLE BOARD PROCESS

FIGURE 21

WASTE PROCESS FOR PANEL BOARD

1. Material Feed
2. Material Storage
3. Feed to Treatment
4. Acid Wash
5. Acid-Water Mix
6. Wet Pre-Former
7. Drier
8. Loading Hoist
9. Hot Press
10. Unloading Hoist
11. Heat Treatment and Humidification
12. Trimming Saws

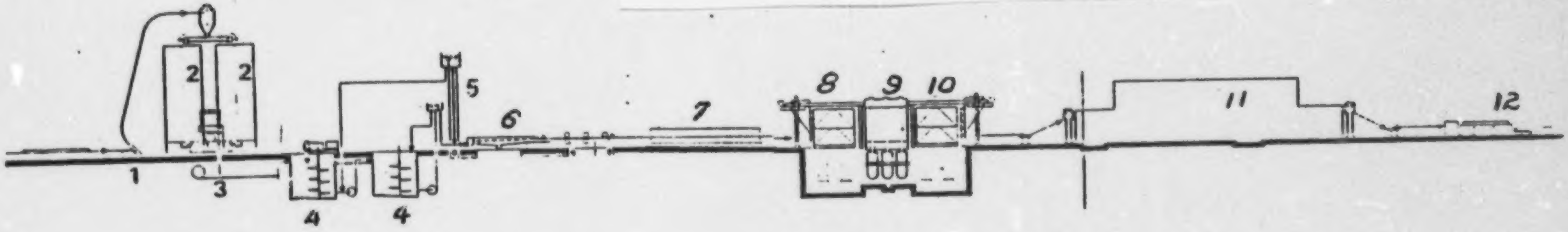


TABLE 46

COMPARISON OF CONVENTIONAL WOOD SHAVING PLANT WITH A RICE HULL OR PEANUT SHELL PLANT

Conventional Wood Shaving Plant*		Rice Hull or Peanut Shell Plant	
Unloading & Storage	120,000	Unloading & Storage	120,000
Milling & Drying	190,000	Acid Wash	100,000
Blending & Forming	490,000	Forming & Drying	150,000
Press Line	1,020,000	Press Line	1,020,000
Finishing Section	350,000	Finishing Section	350,000
Auxiliary Equipment	270,000	Auxiliary Equipment	175,000
Total Equipment Cost	2,440,000	Total Equipment Cost	1,915,000

* Reference (5) - 1967 data

Peanut Shells: $\dfrac{8{,}326/\text{day}}{.037/\text{lb} - (.011\text{lb})(.07 \text{ cost/lb})} = 229{,}809 \text{ lbs/day}$

Wood Chips: $\dfrac{8{,}326/\text{day}}{.038/\text{lb} - (0.10\text{lb})(.07 \text{ cost/lb})} = 223{,}217 \text{ lbs/day}$

8. Assume full production.

The facility costs presented here are based on 200 tons per day of 30 lb/ft^3 board. The plant is volume limited not density limited. Therefore, the more dense panels of 60 lb/ft^3 will permit a production of 400 tons per day. Then the profit is as follows:

Rice Hulls: 800,000 lbs (.041) = $32,800/day Generated
- 8,326/day Fixed Cost
- 392/day Variable Cost
$24,082/day Profit

Peanut Shells: 800,000lbs(.037) = $29,600/day Generated
- 8,326/day Fixed Cost
- 616/day Variable Cost
$20,658/day Profit

Wood Shavings: 800,000lb(.038) = $30,400/day Generated
- 8,326/day Fixed Cost
- 560/day Variable Cost
$21,514/day Profit

9. This would generate on a yearly basis

Rice Hulls: 24,082(260) = $6,261,320

Peanut Shells: 20,658(260) = $5,371,080

Wood Shavings: 21,514(260) = $5,593,640

which would pay off the investment in two years.

10. Production required for a 5 year pay off

Cost per day = $\left(\dfrac{9 \times 10^6}{5 \times 260}\right) + 8{,}326 = \$15{,}249/\text{day}$

Rice Hulls: $\frac{15{,}249}{.041 - (.00049)}$ = 376,518 lbs/day

= 188 tons/day

= 4,230 panels 1/2" x 4' x 8'/day

= 35 MM Sq ft of 1/2" board/year

Peanut Shells: $\frac{15{,}249}{.037 - .00077}$ = 420,894 lbs/day

= 210 tons/day

= 5,071 panels 1/2" x 4' x 8'/day

= 42 MM Sq Ft of 1/2" board/year

Wood Shavings: $\frac{15{,}249}{.038 - .0007}$ = 408,820 lbs/day

= 240 tons/day

= 4,867 panels 1/2" x 4' x 8'/day

= 40 MM Sq Ft of 1/2" board/year

The developed waste process is an economically viable venture. The break-even rate is 110 tons per day or 21.5 million square feet of 1/2 inch board per year, or 671,875 panels 4' x 8' per year. On a full production of 400 tons per day the facility can be paid for in 2 years. On a 5 year pay off about 200 tons per day, or 37 million square feet of 1/2 inch board, or 1,227,893 panels 4' x 8' per year would be required.

The next consideration is the cost required to advance the product from concept to a market accepted product. The estimation of development costs for a product is a complex one and one that is prone to error. There are a multiplicity of steps involved in development. The best approach to establishing a cost would be as follows.

1. Estimate as accurately as possible the cost for each step assuming 100% achievement of projected results.
2. Apply to the above estimate a factor of error. This factor where possible would be derived from similar type development.

The factors to be utilized are developed and are presented in Appendix C. This study is based on the assumption that the processes previously presented will be utilized. The steps to be considered are as follows:

1. Design and qualify a product.
2. Development of the manufacturing procedure.
3. Product application to the market.
4. Establish product acceptance.

Design and qualification for this product is straightforward. The design involves material selection. The qualification requirements are presented in Appendix D. Table 47 summarizes the cost per material per thickness. The inference is that the cost will range from $7,870 to $13,851 per product depending upon the degree of problems that develop.

Development of the manufacturing procedure involves the plant facility, optimization and productization of the panel to achieve reliability and minimum cost possible. The process presented here can utilize an existing particle board facility and its equipment. Therefore, no equipment development is involved. Only processing procedures require development. This, of course, requires the use of an existing particle board line. The cost of manufacturing standard board is approximately $.037/square foot. If it is assumed that an economically viable operation produces 70,000,000 square feet of board per year, then the operation cost per hour is $1,248. Conservatively assume the operational line cost for development is $1500 per hour. The cost of scale up studies, pilot runs, and production start with adjustments to product needs are estimated in Table 48. The estimated cost range is $285,490 to $596,674.

TABLE 47

DESIGN AND QUALIFICATION COST PER ORGANIC MATERIAL PANEL PRODUCT

Technical Services (Includes Burden) (1)	2,800
Required Tests - Mechanical Properties	1,000
Flame Spread	500
Smoke Generation	300
Recommended Tests - Weathering	400
Water Permeability	200
Materials	50
Press Time	50
Tooling	1,000
Filing Fees	570
Travel & Support	1,000
Estimated Cost	$7,870

Probable Cost = Estimated Cost (K_{II}) (2)

= 7,870(1.76)

= $13,851 per product

---

(1) Rate is $21/hr.

(2) See Appendix C for K_{II}

TABLE 48

DEVELOPMENT OF MANUFACTURING PROCEDURE FOR PARTICLE BOARD WASTE PROCESS

A. Scale up Studies		
Technical Services (Includes Burden)	6720	
Process Line Cost (1500/hr)	12000	
Material Cost	50	
		18,770
B. Pilot Run		
Technical Services (Includes Burden)	13440	
Process Line Cost (1500/hr)	60000	
Material Cost	800	
		74,240
C. Start Up and Adjustment to Product Needs		
Technical Services (Includes Burden)	10080	
Process Line Cost (1500/hr) - Assume 75% of product marketable	180000	
Material Cost - Assume 75% of product marketable	2400	
		192,480
Estimated Cost		285,490

Probable Cost = Estimated Cost (K_I) (1)

= 285,490(2.09)

= 596,674

---

(1) See Appendix C for K_I

Application of the product to the market is defined as the steps required to

1. Review and select a market,
2. Evaluate methods of market penetration,
3. Select a method, and
4. Proceed to market.

The cost for the above would depend on the organization involved. In all probability an adequate job could be accomplished for a cost of $50,000 to $60,000.

Product acceptance for this product should be accomplished with a minimal effort. The product is similar in appearance, quality and performance to the existing commercial product and would have ICBO and FHA approvals. Acceptance in this case would be made on price only.

In summary, to get this product on the market a cost of $343,360 to $670,525 could be required. If only wood materials are compared, there is a material saving of $0.025 per square foot of 1/2 inch board. If only half is passed on to the customer, a 70,000,000 square foot production out put would yield $875,000 savings in one year. This would then be reflected in the price of 4' x 8' x 1/2" panels as follows:

	Rice Hulls	Peanut Shells	Wood Chips	Commercial Particle Bd.
(1) Material Cost	0.632	0.898	0.881	1.681
(2) Cost to Mfg. (1.67)(1)+.40*	1.455	1.900	1.871	2.807
(3) Cost to Retailer (1.25)(2)	1.819	2.374	2.339	3.508
(4) Cost at Retail (1.54)(3)	2.802	3.657	3.602	5.402

* Except for commercial particle board, cost to manufacture is 1.67(1).

Based on the above analysis the product development cost can be absorbed in one year and still offer the product on the market at a much lower price than the commercial product.

REPLACEMENT FOR SHEET ROCK

Sheet rock, dry wall, or gypsum board is inexpensive and fire resistant but it is highly susceptible to damage from impact and water. It is believed that the organic waste product can be produced for less or an equivalent cost and would provide a much stronger material. The work here concentrated on producing the lightest material with acceptable strength. Table 49 compares the weight of the peanut shell candidate with sheet rock. Table 50 presents a comparison of strength.

A cost comparison for a 1/2 inch thick 4' x 8' sheet of peanut shell or rice hull organic 55 lb/ft^3 panel with sheet rock is presented below.

	Rice Hulls	Peanut Shells	Sheet Rock
(1) Material Cost	0.519	0.737	0.508
(2) Cost to Mfg. (1.67)(1)	0.867	1.231	0.848
(3) Cost to Retailer (1.25)(2)	1.083	1.538	1.060
(4) Cost at Retail (1.54)(3)	1.668	2.369	1.632

The rice hulls are competitive but the peanut shells would have to be made in a thinner panel to be competitive. Assume a 58 lb/ft^3 peanut shell panel with a 3/8 inch thickness for equivalent to superior strength.

	Rice Hulls(1/2")	Peanut Shells(3/8")	Sheet Rock(1/2")
(1) Material Cost	0.519	0.583	0.508
(2) Cost to Mfg 1.67(1)	0.867	0.973	0.848
(3) Cost to Retailer 1.25(2)	1.083	1.217	1.060
(4) Cost at Retail 1.54(3)	1.668	1.874	1.632

The weight comparison of the panels would be 80 lbs for sheet rock, 73 lbs for rice hulls and 58 lbs for peanut shells. The thickness of rice hulls could be dropped to 3/8 inch also with further process optimization. The performance of rice hull, peanut shell and sheet rock panels when subjected to the E-119 fire test are compared in Figure 22. As can be seen these organic panels compare well with the sheet rock.

The above capabilities combined with screw, and nail retention makes the organic panel very attractive as a wall board. It is also durable, crack resistant and generally more workable with conventional tools than sheet rock.

The process used to manufacture these panels would be similar to that presented in Figure 21. Only a shorter press time of 1 to 2 minutes will be required. This shorter press time would reduce the number of press plattens required for equal production. This would result in a press saving of 30%. Then based on Appendix B data and the previous discussed inflation rate a facility would cost approximately $8,000,000. The following analysis can then be made for this process.

1. Assume the plant cost is $8 million.
2. Material cost is $\$0.016/ft^2$ (rice hulls) and $\$0.018/ft^2$ (peanut shells).
3. Assume sales price to retailer is $\$0.033/ft^2$
4. Generated differences are

    Rice Hulls = $\$0.017/ft^2$

    Peanut Shells = $\$0.015/ft^2$

TABLE ~ 49

COMPARISON OF DENSITIES

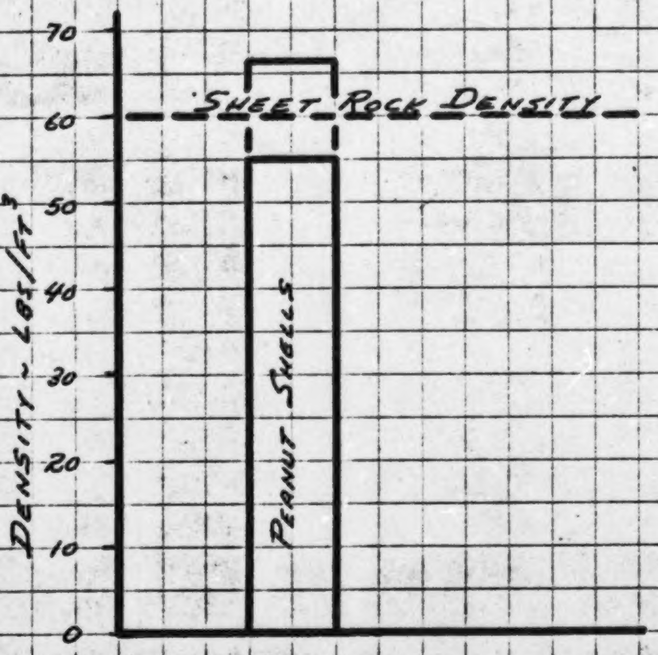


TABLE ~ 50

COMPARISON OF FLEXURE STRENGTH

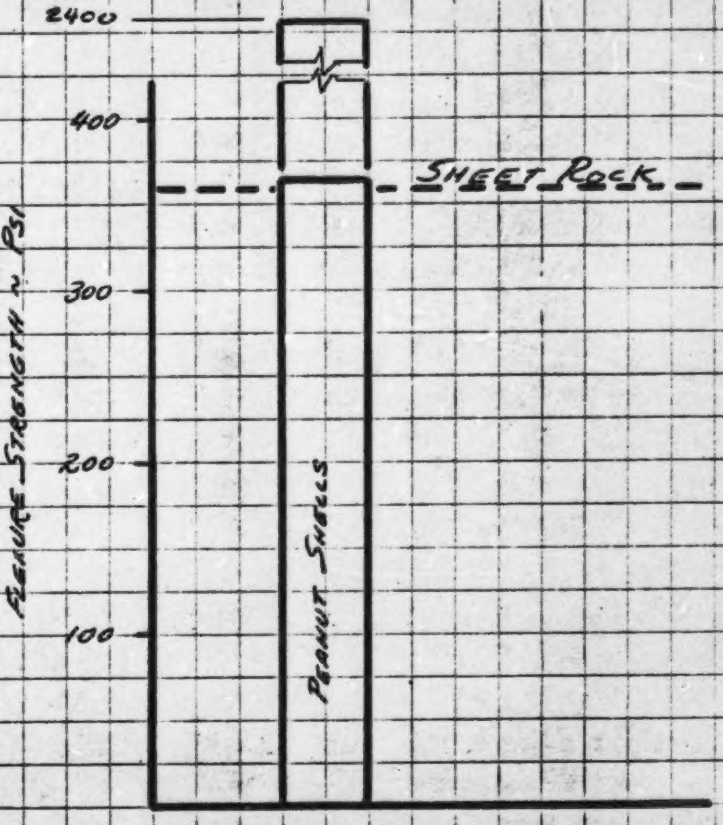
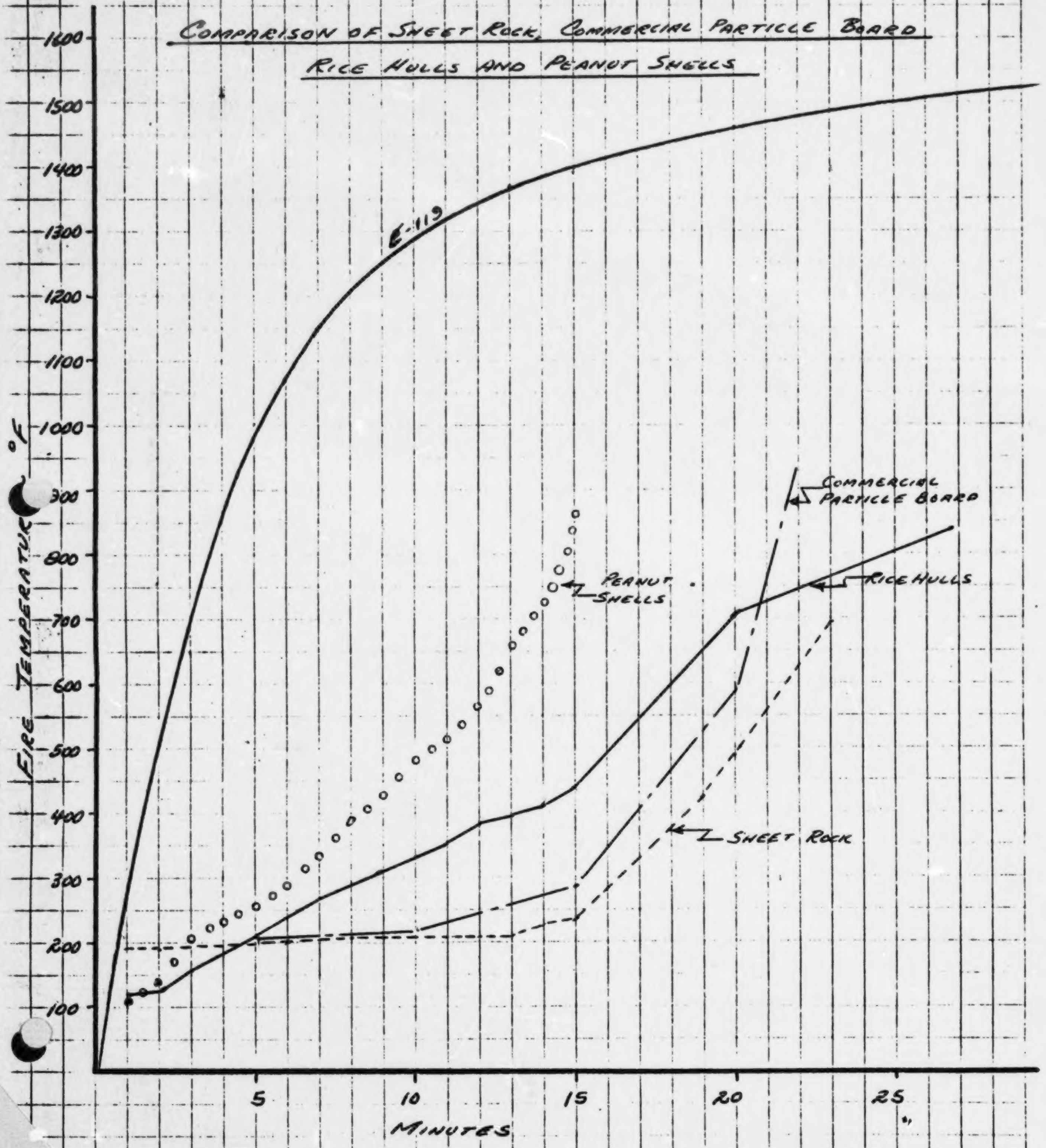


FIGURE ~ 22

COMPARISON OF SHEET ROCK, COMMERCIAL PARTICLE BOARD RICE HULLS AND PEANUT SHELLS



5. The fixed operational costs are as follows:

Labor	$561,000 per year
Maint. & Operational Supplies	275,000 per year
Indirect Costs	429,000 per year
Depreciation	800,000 per year
	2,065,000 per year

Per day costs = $7,942

6. There is an additional 7% material cost added to all production.

7. The breakeven production rate would then be

Rice Hulls $\frac{7,942}{.017 - (.007)(.016)} = 469,940$ sq ft/day

Peanut Shells $\frac{7,942}{.015 - (.007)(.018)} = 533,020$ sq ft/day

8. Assume full production at 800,000 sq ft/day, then the profit is as follows:

Rice Hulls 800,000 sq ft(.017) = 13,600/day Generated

- 7,942/day Fixed Cost

- 80/day Variable Cost

$ 5,578/day Profit

Peanut Shells 800,000 sq ft(.015) = 12,000/day Generated

- 7,942/day Fixed Cost

- 80/day Variable Cost

$ 3,978/day Profit

9. This would generate on a yearly basis

Rice Hulls: 5,578(260) = $1,450,280

Peanut Shells: 3,978(260) = $1,034,280

which would require at a sales price of sheet rock, 7 years to pay off the investment.

The developed waste process is marginal economically if the product is sold on a direct cost basis with sheet rock. If the superior qualities of the organic panel are such to permit a higher sales price to sheet rock, then the product becomes economically feasible.

The next consideration is the cost required to advance the product from concept to a market accepted product. The steps to be considered are the same as particle board which are as follows:

1. Design and qualify a product.
2. Development of the manufacturing procedure.
3. Product application to the market.
4. Establish product acceptance.

Design and qualification for this product is straight-forward also. Engineering consideration must be given to thinner panels for the higher strength and more expensive materials. These trade offs can primarily be accomplished by analytical methods. In all other aspects this would be the same as particle board and Table 47 would apply. The cost for this activity would then range from $7,870 to $13,851 depending on the problems involved.

Development of the manufacturing procedure should be less complex than particle board since mechanical properties are less important. Press time is faster which will reduce cost also. Since an existing particle board facility can be utilized, no equipment development is required. The cost of scale up studies, pilot runs, and production start with adjustment for product needs are estimated in Table 51. The cost range is $202,010 to $422,200.

Application of this product to the market will be more difficult than for particle board. In order to make this project feasible, the organic board will have to be promoted on its superior performance at a higher cost than sheet rock. This marketing should be accomplished through an existing organization with compatible product lines. Marketing is a controlled

TABLE 51

DEVELOPMENT OF MANUFACTURING PROCEDURE FOR LOW STRENGTH PARTICLE BOARD WASTE PROCESS

A. Scale Up Studies		
Tech. Services (Includes Burden)	3,360	
Process Line Cost (1500/hr)	12,000	
Material Cost	50	
		15,410
B. Pilot Run		
Tech. Services (Includes Burden)	10,800	
Process Line Cost (1500/hr)	48,000	
Material Cost	600	
		58,680
C. Start Up and Adjustment to Product Needs		
Tech. Services (Includes Burden)	6,720	
Process Line Cost (1500/hr) - Assume 75% of Product Marketable	120,000	
Material Cost - Assume 75% Product Marketable	1,200	
		127,920
Estimated Cost		202,010

Probable Cost = Estimated Cost (K_I) (1)

= 202,010(2.09)

= 422,200

---

(1) See Appendix C for K_I

cost (See Appendix C) but when performance and not cost is the sales feature, it can be expensive. An estimate of $250,000 is projected for this activity.

Product acceptance for this product will be easy once the additional cost over sheet rock is justified. Since the product would have code approval and would be surface treated to the same appearance as existing structures, the superior properties would make the product easily acceptable.

In summary to get this product on the market a cost of $459,880 to $686,051 would be required. Before initiating such an activity, a very complete marketing analysis would be required to determine the additional cost that the market would sustain for a superior product to sheet rock. This cost would then have to be compared with the development costs involved to establish economic feasibility.

LUMBER SUBSTITUTE

The requirements for a product as a direct lumber substitute are as follows:

1. Equivalent strength
2. Equivalent nail and screw retention
3. Dimensional stability
4. Workable with carpenter type tools.

There have been a variety of commercial approaches to this concept such as US Plywood's Novoply. These usually consist of fiber oriented dense outer skins on either side of a low density core. The costs are not usually too competitive with ordinary lumber. The advantages of these materials over lumber are the utilization of waste and dimensional stability.

The only active work done in this study to determine the applicability of the waste process to a lumber substitute was to determine workability and screw and nail retention. All organic formulation worked with were easily workable with conventional saws, drills, etc. Table 52 presents a comparison of wood and nail retention. The cost of a 2" x 4" from organic would be $0.037 per foot for material and would retail for $0.120 per foot. This compares very well with the $0.15 to $0.20 per foot for conventional 2" x 4".[6]

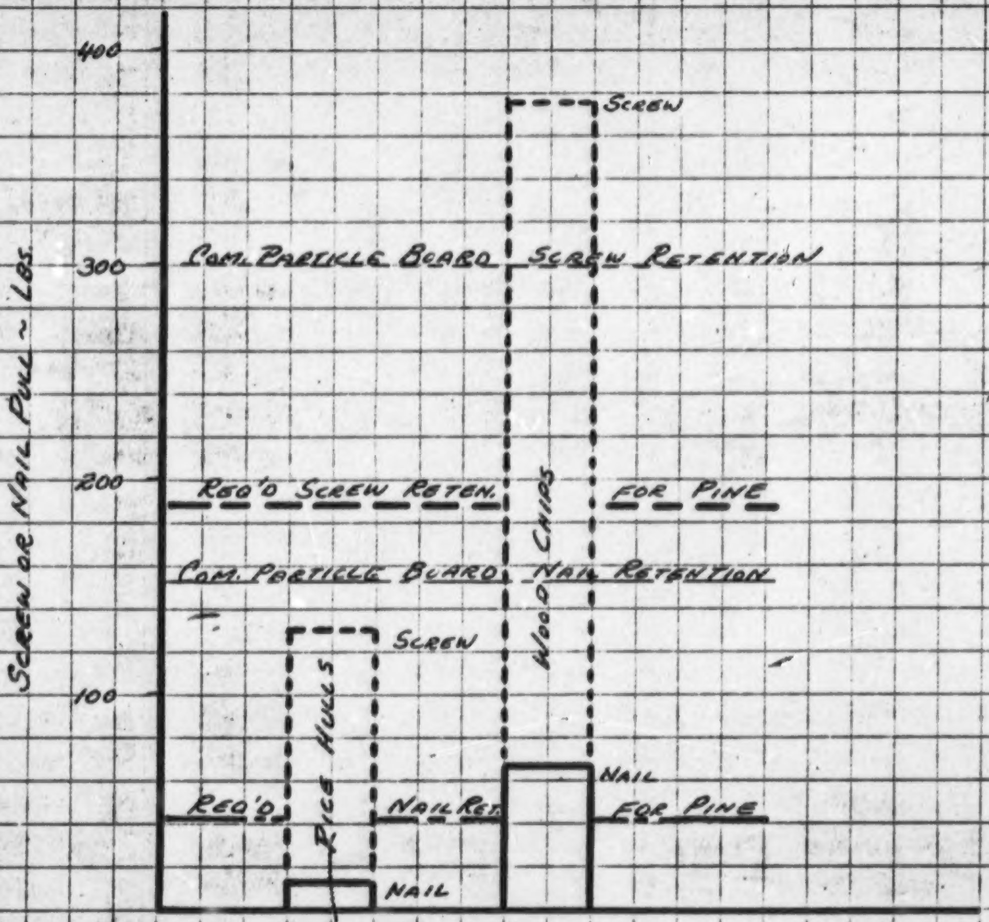
There would have to be more engineering development on fiber orientation or improved reinforcement before the material could be considered as a lumber replacement. The strength properties of the dense peanut shells and wood chips with this process is equivalent to that of pine lumber or Douglas Fir. The material would be produced in a continuous press or extrusion system designed for shapes. The process would be the same as that shown in Figure 20 except the preformer, dryer, loading hoist, press, and unloading hoist would be re-designed for a continuous feed process. An estimate of the equipment cost based on the same 1967 base as that shown in Table 46 is presented in Table 53. Then based on Appendix B data and the previous discussed inflation rate a facility would cost approximately $4.5 million. The following analysis can then be made for this process.

1. Assume the plant cost is $4.5 million.
2. Material cost is $0.055 per board foot.
3. Assume sales price to retailer is $0.195 per board foot.
4. Generated difference is $0.14 per board foot.
5. The fixed operational costs as as follows:

Labor	420,000 per year
Maint. & Operating Supplies	275,000 per year
Indirect Costs	322,000 per year
Depreciation	450,000 per year
	1,467,000 per year

Per day costs = $5,642

TABLE ~ 52
SCREW AND NAIL RETENTION



6. The break even production rate would then be

   Board feet per day: $\frac{5642}{0.14} = 40,300$

   This is sufficient lumber for 5 houses per day.

7. Assume full production is 500,000 board feet per day, then the profit is as follows:

Generated Income:	500,000(.14) =	70,000
Costs		5,642
Profit		64,358

8. This would generate on a yearly basis an income of $16,733,000.

Since the production equipment is yet to be designed, the total available output is questionable. However, assuming the product can be marketed on a direct competitive basis, the lumber substitute does appear to have promise.

The consideration involved in advancing this product from concept to market will be slightly more involved than the particle board operation. However, the same basic steps are involved.

Design and qualification will require some improvement in strength and nail and screw retention as well as the qualification tests. A summary of cost estimates are presented in Table 54. The costs for this activity would range from $31,070 to $54,683.

Development of the manufacturing procedure is more complex than before because the press line must be developed to make this system economically viable. The details are summarized in Table 55. The development of the press system is a large unknown value with the limited information that is presently available. Also this would require in all probability a new facility. Therefore, the cost for this activity would range from $3 million to $6.3 million.

TABLE 53

ESTIMATE OF CONTINUOUS SHAPE FACILITY

Unloading and Storage	120,000
Acid Wash	75,000
Preforming Into Line	150,000
Press line - Continuous	250,000
Finishing Section	150,000
Auxiliary Equipment	100,000
	$845,000

TABLE 54

DESIGN & QUALIFICATION COST FOR LUMBER SUBSTITUTE

Technical Services (Includes Burden)	$16,800
Required Tests - Mechanical Properties	1,000
- Flame Spread	500
- Smoke Generation	300
Recommended Tests - Weathering	400
Materials	500
Press Time	5,000
Tooling	5,000
Filing Fees	570
Travel & Support	1,000
Estimated Cost	$31,070

Probable Cost = Estimated Cost (K_{II}) (1)

= 31,070 (1.76)

= $54,683

---

(1) See Appendix C

TABLE 55

DEVELOPMENT OF MANUFACTURING PROCEDURES FOR LUMBER SUBSTITUTE

A. Process Development		
Technical Services (Includes Burden)	43,680	
Laboratory Equipment	50,000	
Material Cost	500	
		94,180
B. Scale Up Studies		
Technical Services (Includes Burden)	43,680	
Process Line Purchase	475,000	
Material Cost	1,000	
		519,680
C. Pilot Run Studies		
Technical Services (Includes Burden)	43,680	
Additional Line Purchases	370,000	
Process Line Operation (1000/1b)	160,000	
Material Costs	5,000	
		578,680
D. Start Up and Adjustment to Product Need		
Technical Services (Include Burden)	43,680	
Additional Equipment	1,660,000	
Process Line Cost (1000/hr) - 75% Market.	80,000	
Material Cost - 75% Marketable	23,827	
		1,807,507
Estimated Total		$3,000,047

Probable Cost = Estimated Cost (K_I)(1)

= 3,000,047 (2.09)
= $6,270,098

(1) See Appendix C

Application of this product to the market will require the demonstrateable proof of direct lumber substitution. The marketing should be accomplished through an existing wood products distribution system. The cost can be regulated by the marketing plan but a reasonable estimate of cost would be $125,000.

Product acceptance for this product will have to come through trial projects with builders. Therefore, some subsidization may be required to create acceptance. A cost of $250,000 may be a reasonable estimate.

In summary to get this product on the market a cost of $3.4 to $6.7 million may be incurred. However, if the market can sustain a 500,000 board feet per day production, this cost could be recovered in one year. This would be unlikely as the product would have to be introduced slowly into the market.

FIRE DOORS

There exists a major requirement in the developing building standards for fire doors which will perform in excess of 1 hour. A blank of 1 1/2 inch thick rice hulls, peanut shells or wood chips produced from the waste process would perform for at least 2 hours and possibly 3 hours. This is based on extrapolating the 1/2 inch thick fire data to 1 1/2 inch using the relationship curve of thickness on fire resistance presented in the section on products from inorganic materials.

The molded blank could be machined by routine door equipment. The surface is of a wood appearance requiring no veneer. Hardware can be installed directly into the blank. A standard 3' x 6'8" door would have a material cost of $1.17 to $1.67 with a cost to the retailer of $2.44 to $3.49. The door industry at this time pays $12 for a core which then has to have stiles, rails, crossbands, and veneer or plastic surfaces applied.

If it is assumed that the particle board facility described earlier was capable of handling 1 1/2 inch blanks, then the following cost analysis can be made.

1. A door utilizes 150 lbs of material.
2. The material cost for a door is \$1.67.
3. Assume sales to retailer is the same as the present core sales, i.e. \$12 per door.
4. The generated difference is \$10.33 per door.
5. The operational costs are \$8,326 per day.
6. The breakeven production rate would then be

   Doors per day = $\frac{8,326}{10.33}$ = 806.

7. Assume a production rate of 2500 doors per day.

   Generated Sales = 25,825

   Operation Cost = 8,326

   Profit 17,499 per day

8. This would generate a yearly sales of \$4,549,740.

If sufficient market was available for doors, this would be an excellent product for a panel plant.

The activities required to take this product from concept to the market will involve those previously discussed. Since the particle board facility and this requirement is compatible, it will be assumed that the fire door is an addendum product to that of the board.

Design and qualification requires consideration of hinge and latch attachment and fire resistance. The design would be based on the material selected for the particle board plant. A summary of cost estimates are presented in Table 56. The cash for this activity would range from \$17,750 to \$31,240.

Development of the manufacturing procedure will be based on the assumption that particle board is already being produced. Therefore, the development will be based on the molding of 1 1/2 inch to 1 3/4 inch blanks. These

TABLE 56

DESIGN AND QUALIFICATION FOR A FIRE DOOR

Technical Services (Includes Burden)	10,080	
Required Test - ASTM-E-152 (for Fire Doors)	2,500	
Materials	200	
Press Time	400	
Tooling	3,000	
Filing Fees	579	
Travel and Support	1,000	
Estimated Cost		$17,750

Probable Cost = Estimated Cost (K_{II}) (1)

= $17,750 (1.76)

= $31,240

---

(1) See Appendix C

costs are summarized in Table 57. This activity will cost from $102,075 to $213,336 depending on complexities.

Application of this product to the market will be relatively simple since the door will have code approval and the price is extremely competitive. This should also be accomplished through an existing wood products distributor. The marketing cost can be regulated and could be limited to $50,000.

Product acceptance should not be difficult as the resulting door will not appear different than present products. The expenses incurred will be that of a standard nature associated with any product line.

In summary to achieve a market with this fire door a cost of $169,825 to $294,576 will be incurred. This cost can easily be recovered in one year of fire door production.

TABLE 57

DEVELOPMENT OF MANUFACTURING PROCEDURES FOR FIRE DOORS

A. Scale Up Studies		
Technical Services (Includes Burden)	6,720	
Process Line Cost (1500/hr)	12,000	
Material Cost	50	
		18,770
B. Pilot Run		
Technical Services (Includes Burden)	6,720	
Process Line Cost (1500/hr)	36,000	
Material Cost	500	
		43,220
C. Start Up and Adjustment to Product Needs		
Technical Services (Include Burden)	6,720	
Process Line Cost (1500/hr) Assume 75% of product marketable	30,000	
Material Cost - Assume 75% marketable	3,365	
		40,085
Estimated Cost		$102,075

Probable Cost = Estimated Cost (K_I) (1)

= 102,075(2.09)

= 213,336

---

(1) See Appendix C

PRODUCTS INORGANIC MATERIALS

There are a variety of products conceivable from the inorganic materials developed here. The ones evaluated in this program with the most promise are as follows:

1. Fire Rated Partition Wall
2. Floor/Ceiling System
3. Fire Door Core

Also evaluated with minimal success were framing materials and ceiling panels. Other products which would be a derivative from the partition wall would be

1. Interior Wall Panels,
2. Floor Systems,
3. Ceiling Systems, and
4. Roof Systems.

Each of these are discussed in detail in the following text.

FIRE RATED PARTITION WALL

The design criteria for the partition wall is presented in Appendix E. The first design concept for such a panel is presented in Figure 23. Rice hull syntactic foam formulation RH-31 (Table 37) was selected for this study. The finished specimen is shown in Figure 24.

Although fire does not penetrate through the rice hull surface, the back temperature gets as high as 380°F. The structural corrugation that carries the required loads was designed and made from glass reinforced inorganic matrix to which the rice hull insulation is bonded, either directly when fabricated or with heat-resistant epoxy adhesive.

This specimen was tested in flexure and the results are presented in Figure 25. The system was superior to that of the present MSC qualified structural

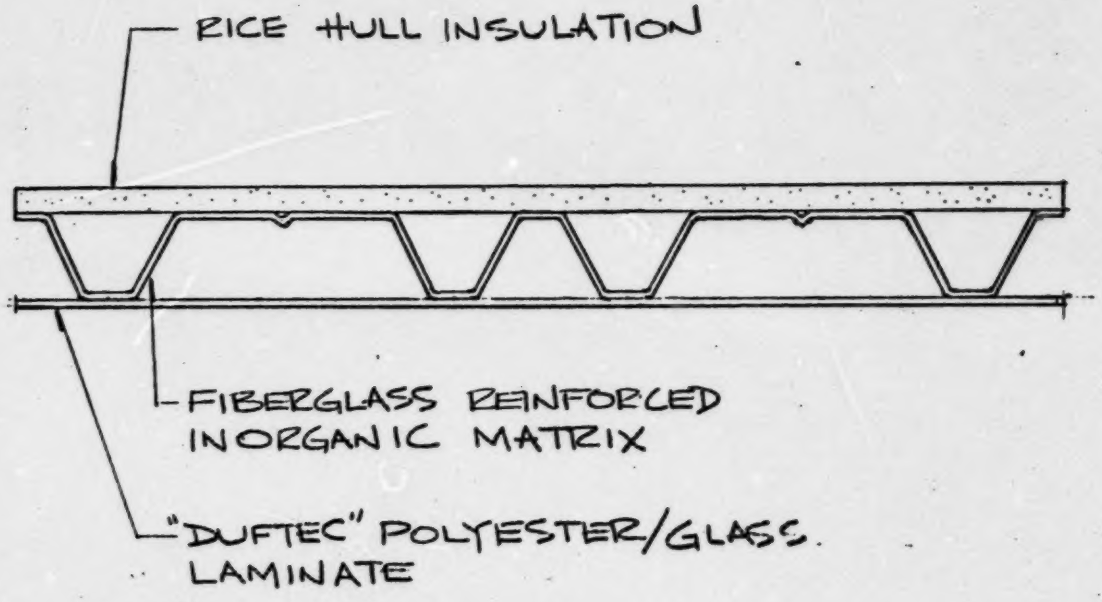

RICE HULL INSULATION
FIBERGLASS REINFORCED INORGANIC MATRIX
"DUFTEC" POLYESTER/GLASS LAMINATE

FIG. 23 SECTION - PROPOSED FIRE WALL

SCALE: NONE

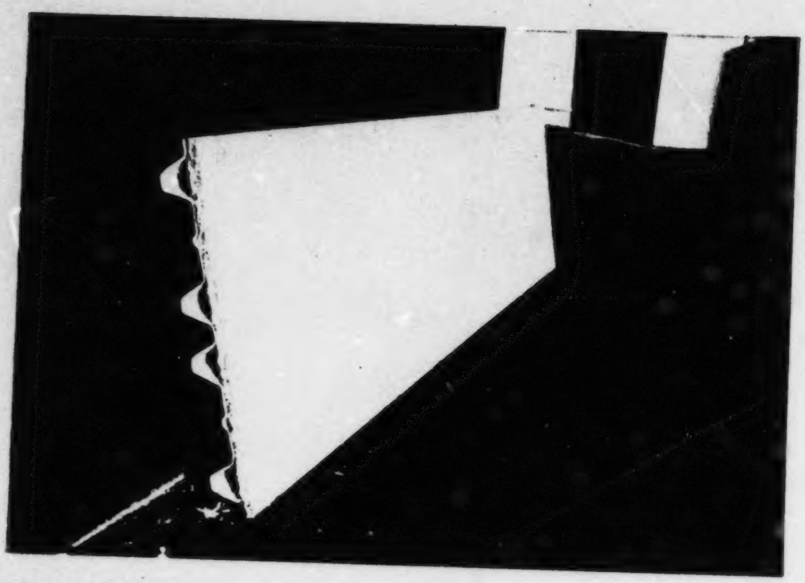


Fig. 24 Fire Wall, Preliminary Model (Without Duftec Skin)

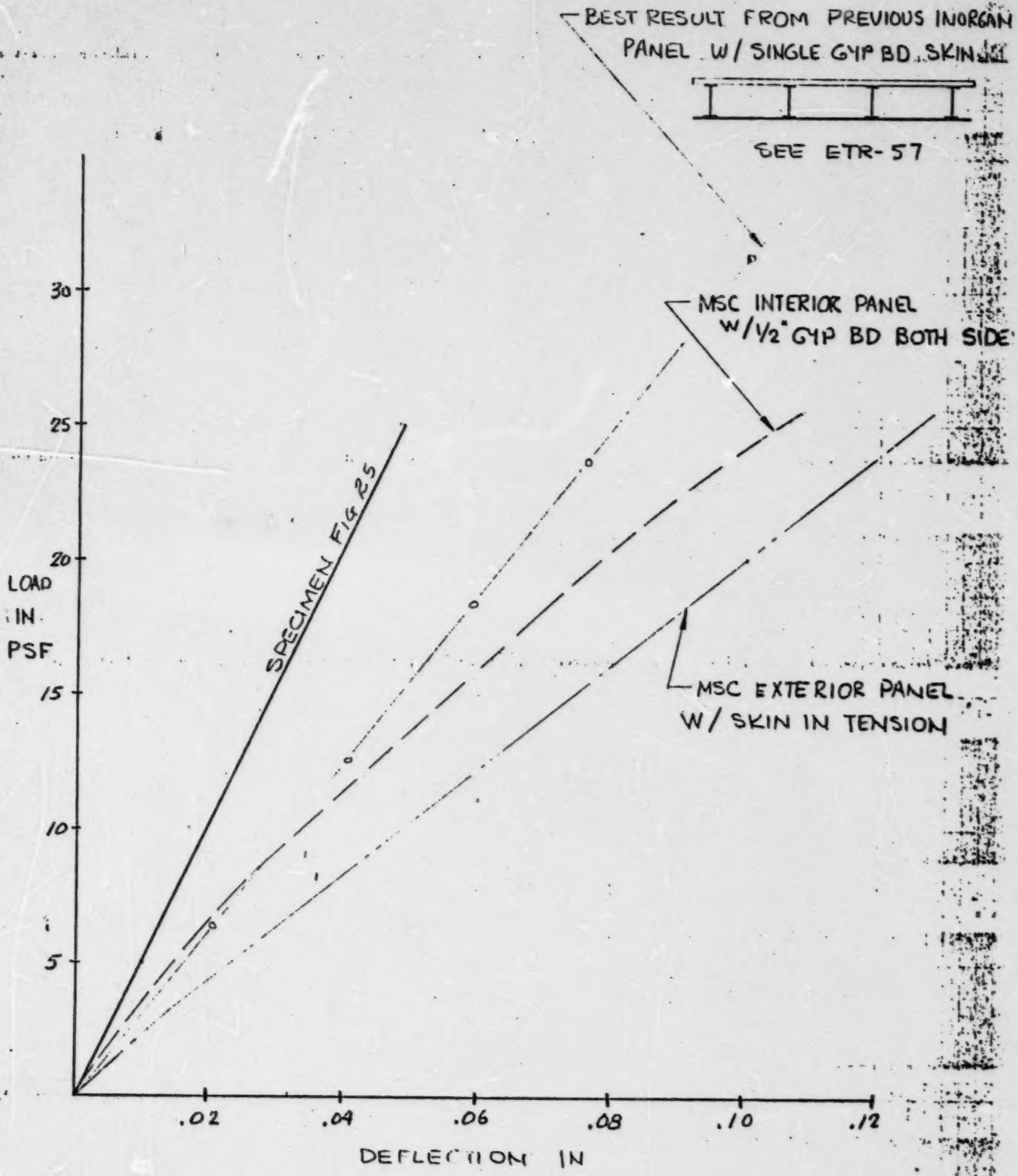


FIG 25
FLEXURAL LOAD

wall. However, the fiberglass polyester inner skin softens and burns at the higher temperature. It was, therefore, decided to construct an all inorganic system.

This design utilized RH-31 also was constructed as shown in Figure 26. The sequence of construction for the wall are shown in Figures 27, 28, 29, 30, 31, 32, and 33. The panel was tested in both flexure and compression. Flexure load vs deflection is shown in Figure 25. As can be seen it is considerably stiffer than any of the previous qualified panels. Figure 34 presents the comparison in compression of this panel with structurally qualified panels. Details of the test are presented in Appendix F.

A detailed cost analysis of this concept installed versus a standard wall installed is presented in Table 58. As can be seen the installed cost of the waste system is 49% that of a conventional system. This wall is overdesigned and may be further optimized to reduce cost.

The inorganic glass pan as can be seen in Table 58 represents more than 50% of the material cost. It was decided to determine the effect of this pan on the strength of the panel. A panel was made as shown in Figures 26 through 33 but without the fiberglass pan. This wall failed at 1000 #/ft load when the bond between the two halves failed. The next logical step is to construct the panel in one piece. This technique will be studied in Phase III.

Two modified E-119 fire tests were conducted on the panel shown in Figure 26. After three hours the fire begins to penetrate through the surface of the face exposed to the fire. The results of the two tests are shown in Figure 35. The first test was terminated after 145 minutes because of a fuel malfunction.

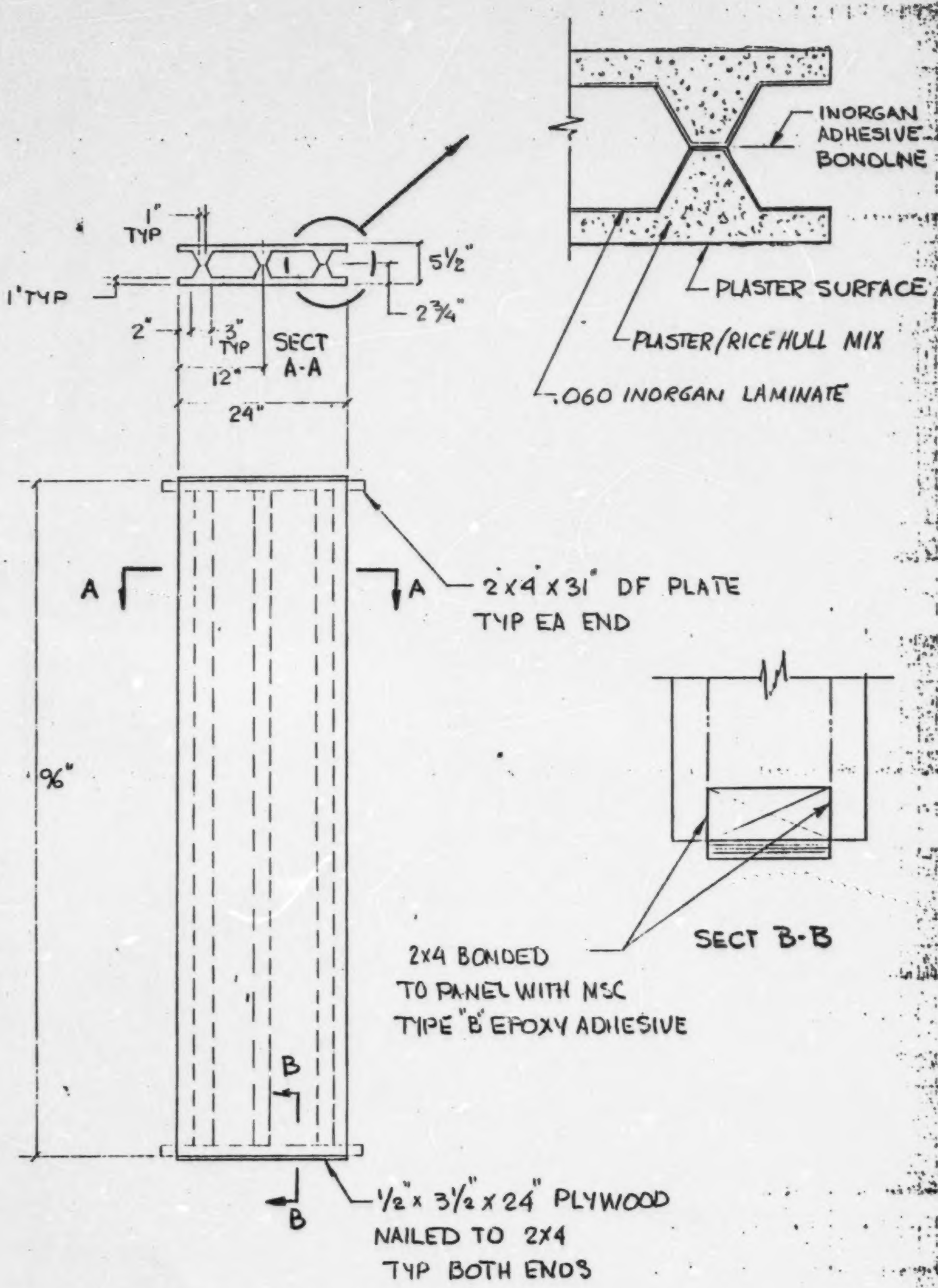

1" TYP
1' TYP
5½"
2¾"
2"
3" TYP
12"
SECT A-A
24"
INORGAN ADHESIVE BONDLINE
PLASTER SURFACE
PLASTER/RICE HULL MIX
.060 INORGAN LAMINATE
A
A
2x4x31" DF PLATE TYP EA END
96"
SECT B-B
2x4 BONDED TO PANEL WITH MSC TYPE "B" EPOXY ADHESIVE
B
B
½" x 3½" x 24" PLYWOOD NAILED TO 2x4 TYP BOTH ENDS

FIGURE 26

FIRE RATED PARTITION WALL

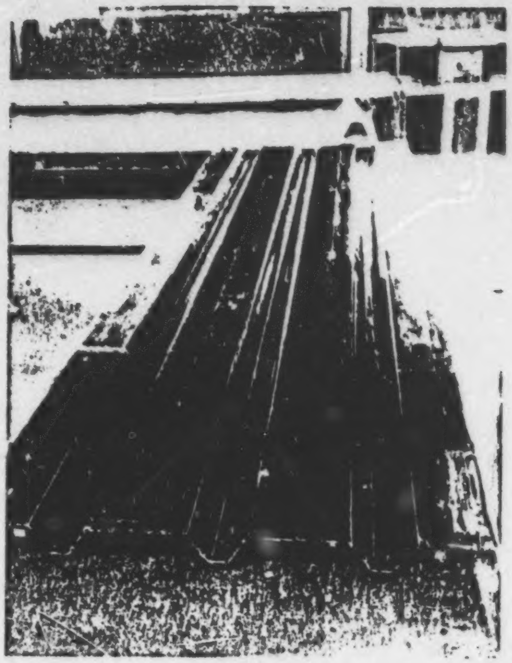


Figure 27: Fiberglass Mold for Syntactic Foam Panel, Lay-up

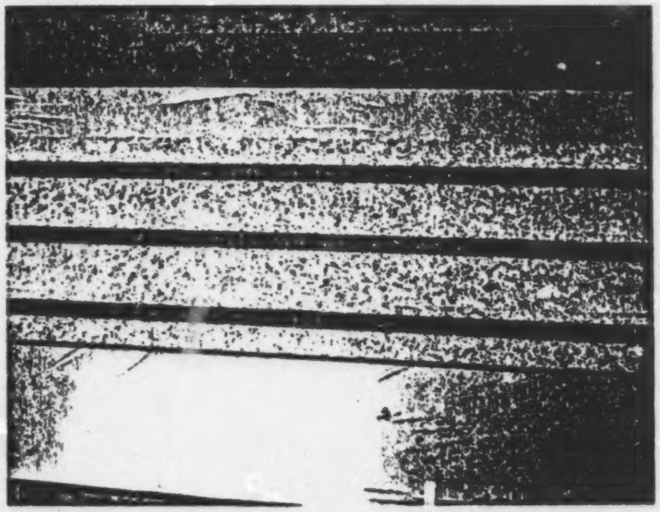


Figure 28: Rice Hulls Syntactic Foam Panel, Removed From Mold

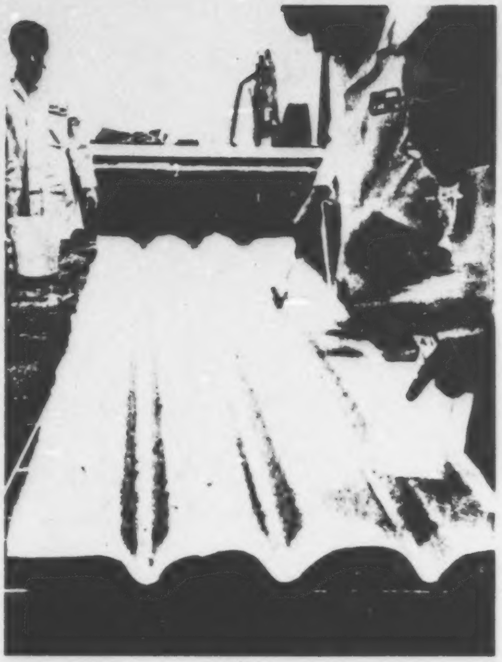


Figure 29: Lay-up of Inorgan/glass Laminate in Fiberglass Mold

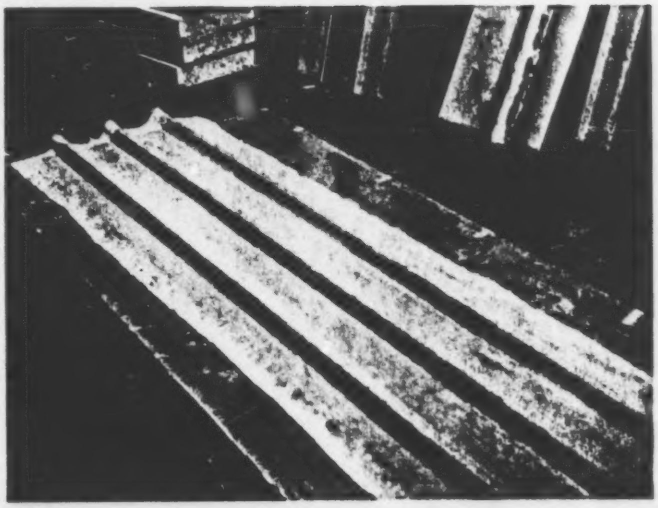
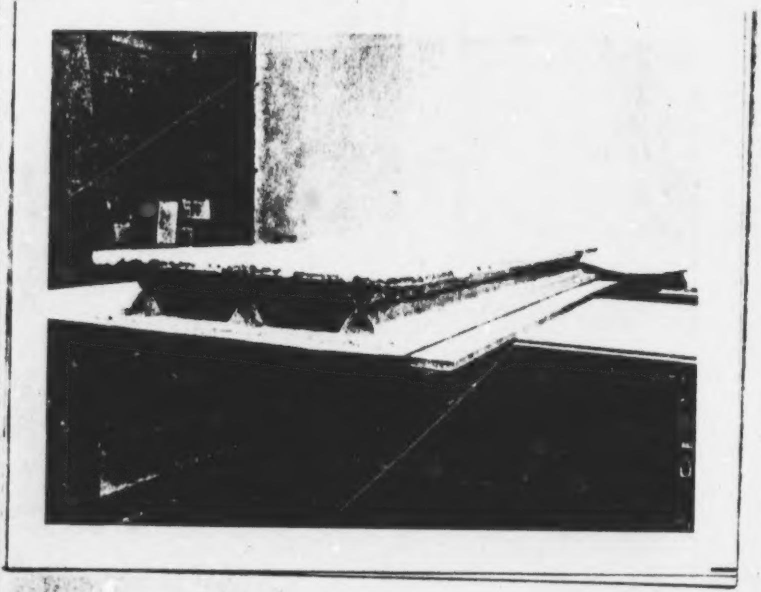


Figure 30: Half of Fire Wall Panel, Removed from Mold



Figures 31, 32, & 33 : Assembled Fire Wall Panel

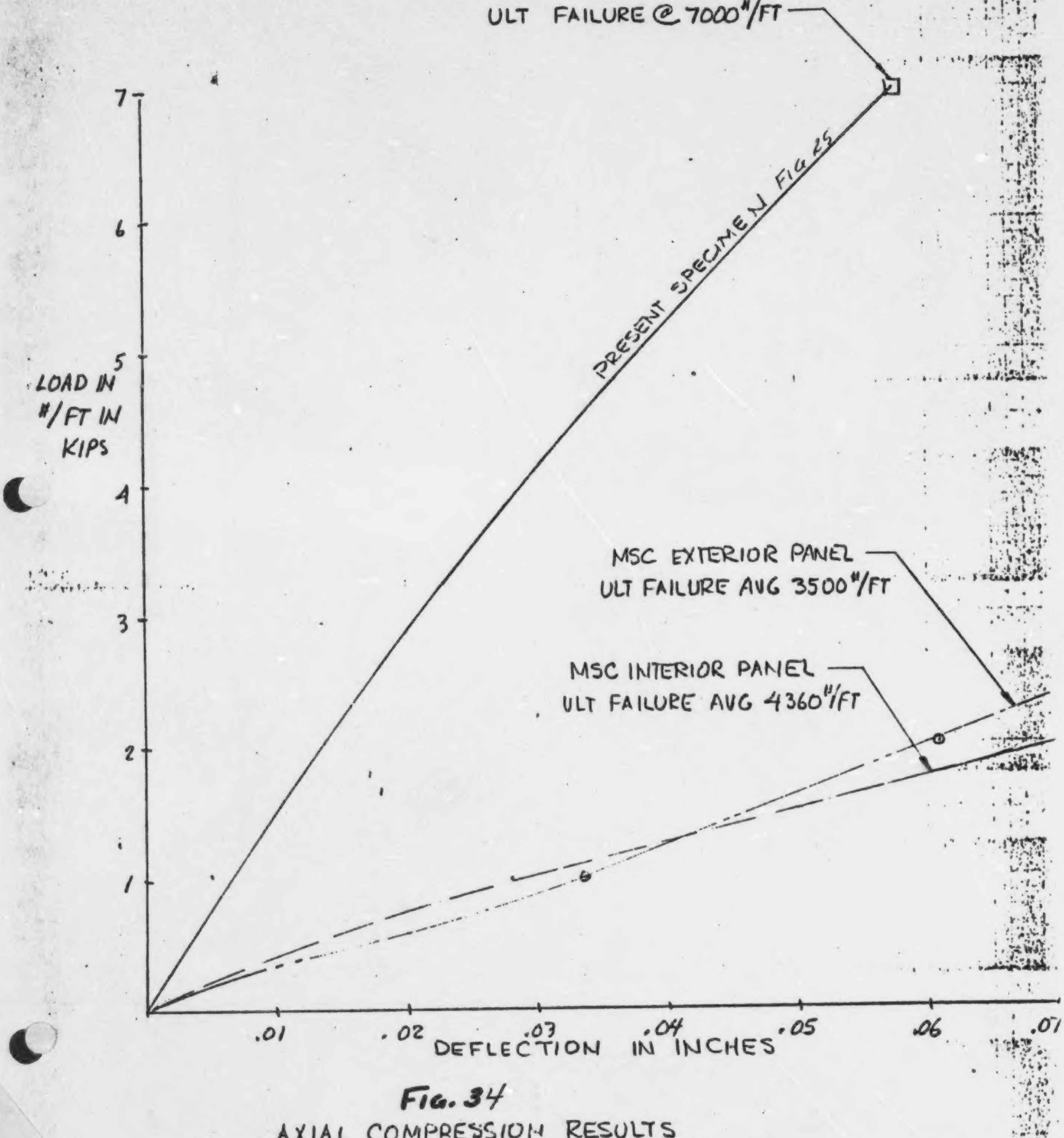


Fig. 34
AXIAL COMPRESSION RESULTS

Table 58

Cost Comparison of a 2-Hour Fire Wall

Waste Wall Concept

Glass & Plaster	$ .030
Rice Hull Foam (.129 ft^3) (1.50)	.194
Inorganic Glass Pan (2.79) (.112)	.312
Adhesive (.079 lb.) (.30)	.024
Material Cost	$0.560/ft^2
Labor, Depreciation, etc. for Assembly	0.159
Field Installation Labor	0.156
Total Cost	$ .875/ft^2

Standard Wall (2-Hour Rating)

2 Double Layer of ½" Sheet Rock	.24
Clips and MSC Hardware	.06
2 - 2" x 4" @ .18	.36
	.66/ft^2
Labor - Framing (1) 2(.30)	.60/ft^2
Drywall Sheathing (1) 4(.132)	.53/ft^2
	$ 1.79/ft^2

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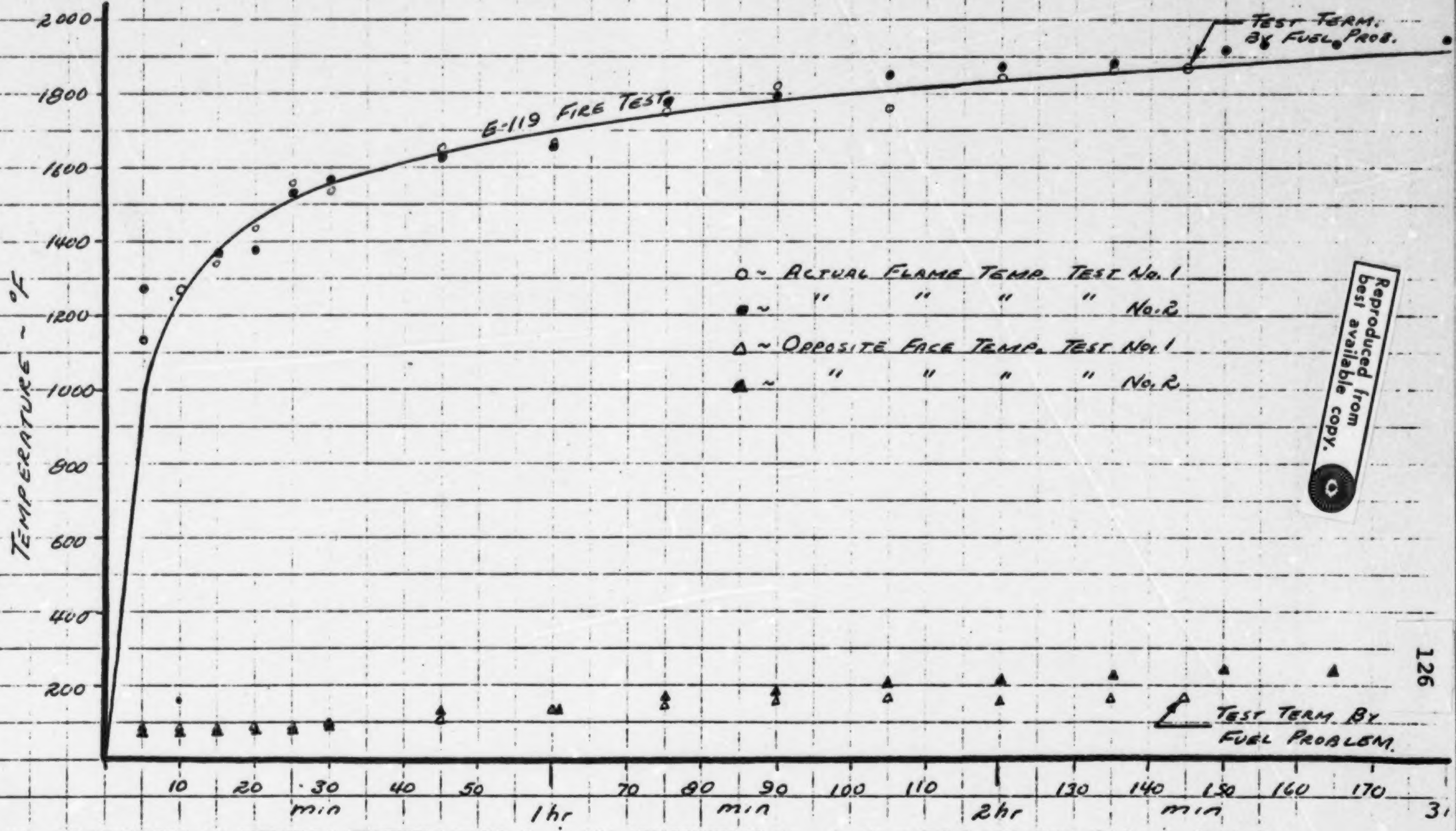
(1) Lee Saylor, Inc. Construction Costs

FIGURE ~ 35

E-119 FIRE TEST - STRUCTURAL PARTITION WALLS



○ ~ ACTUAL FLAME TEMP. TEST No. 1
● ~ " " " " No. 2
△ ~ OPPOSITE FACE TEMP. TEST No. 1
▲ ~ " " " " No. 2

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This material is processed similar to concrete. Therefore, continuous concrete panel production machinery should be applicable. The next consideration is the cost required to advance the product from concept to a market accepted product. The cost for this is discussed below utilizing the factors presented in Appendix C.

Design and qualification for the fire rated partition wall is straightforward. The design work remaining is optimization. The qualification requirements are presented in Appendix D. Table 59 summarizes the cost. This activity will range from $14,430 to $25,397. However, the material and design is such that an estimate half way between would be conservative.

Development of the manufacturing procedure involves the plant facility, optimization and productization of the panel to achieve reliability and minimum cost possible. This process will utilize standard concrete manufacturing equipment with some modification yet to be determined. The cost of scale up studies, pilot runs, and production start with adjustments to product needs are estimated in Table 60. The estimated cost range is $79,600 to $144,076.

Application of the product to the market is defined as the steps required to

1. Review and select a market,
2. Evaluate methods of market penetration,
3. Select method, and
4. Proceed to market.

The cost for the above would depend on the organization involved. This system will require an organization close to a manufacture of housing or housing elements. In all probability, the product would be incorporated into an existing system. A cost of $75,000 should be conservative estimate.

TABLE 59

DESIGN AND QUALIFICATION COST FOR THE FIRE WALL

Technical Services (Includes Burden)	3,360
Mechanical Tests -	5,000
Axial Compression	
Transverse Loading	
Racking Shear	
Impact	
E-119 Fire Test	2,500
E-84 Tunnel Test	800
Smoke	
Flame	
Materials	200
Tooling	1,000
Filing Fees	570
Travel & Support	1,000
Estimated Cost	14,430

Probable Cost = Estimated Cost $(K_{II})^{(1)}$

= 14,430(1.76)

= 25,397

---

(1) See Appendix C for K_{II}

TABLE 60

DEVELOPMENT OF MANUFACTURING PROCEDURE FOR THE FIRE WALL

A. Scale Up Studies		
Technical Services (Includes Burden)	6,720	
Equipment Cost ($150/hr)	6,000	
Material Cost	1,000	
		13,720
B. Pilot Run		
Technical Services (Includes Burden)	6,720	
Equipment Cost ($150/hr)	6,000	
Material Cost	3,000	
		15,720
C. Start Up and Adjustment to Product Needs		
Technical Services (Includes Burden)	13,440	
Equipment Cost ($150/hr) Assume 75% of product marketable	6,000	
Material Cost - Assume 75% of product marketable	30,720	
		50,160
Estimated Cost		79,600

Probable Cost = Estimated Cost $(K_I)^{(1)}$

= 79,600(1.81)

= $144,076

---

(1) See Appendix C for K_I

Product acceptance for this product will be based on its ability to perform as a fire rated structure. Its appearance will be similar to that of any ordinary plastered wall. Therefore acceptance will come through the builder and not the public. This will necessitate some trial projects and some subsidization may be required to create builder acceptance. A cost of $250,000 may be a reasonable estimate.

In summary to get the fire wall on the market a cost of $419,030 to $494,473 will be incurred.

FLOOR/CEILING SYSTEM

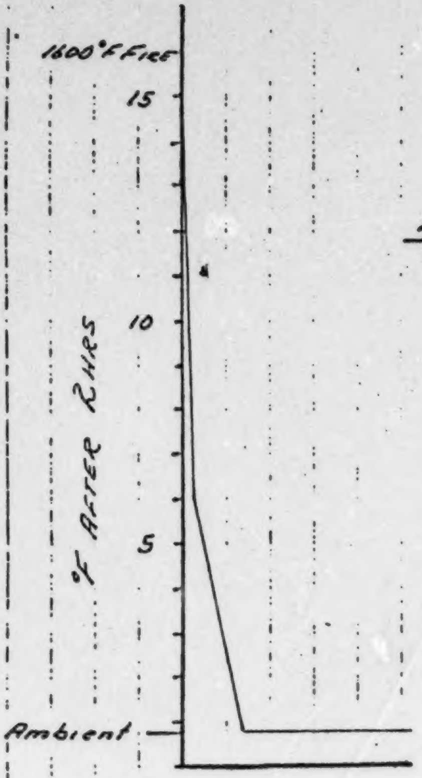
The design criteria for the floor or floor/ceiling system is presented in Appendix G. The wall panel Figure 26 was tested as a floor. The relationship of load vs. deflection is presented in Figure 25.

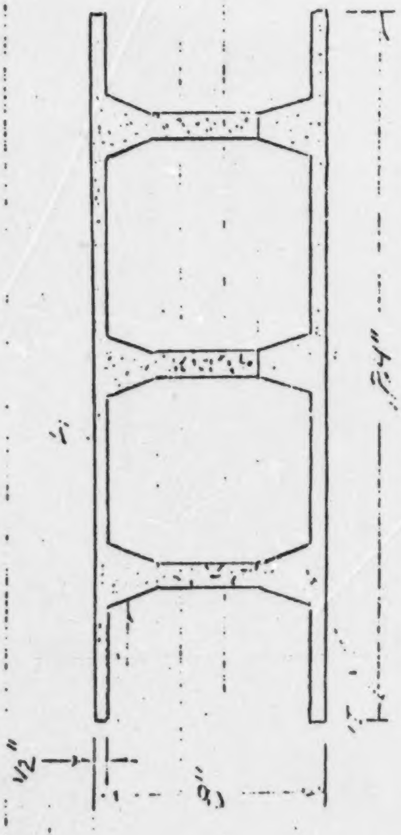
The 8-foot panel was only loaded to 25 pounds per square foot, but the deflection is linear. Therefore, the deflection at 45 pounds per square foot would be 0.09 inches. The criteria for stiffness is $\Delta = L/360$ or for 8 feet, $\Delta = .267$ inches. Therefore, this panel is nearly 3 times as stiff as required. Figure 36 presents an analysis for a 12-foot span floor/ceiling concept. This design is still nearly twice as stiff as required. After 2 hours, the first two inches of the panel can be assumed to be destroyed. At that time the panel is still capable of supporting a full 45 pounds per square foot live load plus the weight of the remaining structure. However, the 3 hour fire test shown in Figure 35 only destroyed the first 1/2 inch of the surface which makes the concept exceptionally strong and fire resistant. Table 61 presents a cost comparison of this concept versus two standard floor/ceiling concepts. The waste concept is 62% of the cost of a standard wood construction and 59% of the cost of a concrete slab system.

FIGURE 36

FIRE AND STRENGTH REQUIREMENTS

WASTE FLOOR/CEILING CONCEPT





Deflection Criteria $\Delta \leq \frac{l}{360}$
Use a 12' Span
45 lb. Live Load + 8.87 lb. Dead Load
$I = 219 \text{ in}^4$
$\Delta = 0.23$ in Criteria ≤ 0.40 in

Assume Fire makes 2" non-structu
Effective $I = 32.54 \text{ in}^4$

$\sigma = 1{,}297$ psi Allow. $\sigma = 1{,}998$ psi

Table 61

Cost Comparison of a 2-Hour Fire Rated Floor/Ceiling Panel

Waste Floor/Ceiling Concept

Glass & Plaster	$ .030
Rice Hull Foam (.174 ft^3) (1.50)	.261
Inorganic Glass Pan (2.79 ft^2) (.112)	.312
Adhesive (.079 lbs.) (.30)	.024
Material Cost	$ 0.627/ft^2
Labor, depreciation, etc. for Assembly	0.171
Field Installation Labor	0.208
Total Cost	$ 1.0061/ft^2

Standard Floor/Ceiling - Wood Construction(1)

1 Double layer of ½" Sheet Rock	.12
2 - 2" x 6" @ .27	.54
1 Layer ½" Plywood	.30
Clips and Misc. Hardware	.06
Material Cost	$ 1.02/ft^2
Labor - Framing	0.250
Labor - Plywood Sheathing	0.090
Labor - Drywall Sheathing 2(.132)	0.264
Total Cost	$ 1.624/ft^2

Standard Floor/Ceiling - Concrete Construction(1)

Forms (including labor)	0.027
Structural Concrete (including labor)	0.579
Rough Finishes (including labor)	0.190
2-Hour Fire and Acoustic Insulation System (including labor)	0.900
Total Cost	$ 1.696/ft^2

---

(1) Lee Saylor, Inc. Construction Costs

There is a definite need for both the 2-hour rated fire wall and floor/ceiling combination in today's construction. There is a special safety need in multi-family construction. It is proposed to design the wall as a standard 4' x 8' panel with interlocking attachments designed to fit over standard 2" x 4" sill plates. The material can be cut with a standard carbide power saw which permits wall closeouts and adjustments for doors and windows. The panel will weigh less than 200 pounds which permits it to be handled by two men. It can also be prefinished in the factory. The joints can be filled in with inorganic matrix with a compatible texture.

It is proposed to design the floor/ceiling panel in standard two feet widths with varying lengths. These panels would be interlocking with end attachments designed for standard footings or floor beam construction. These panels would weigh less than 200 pounds also, which permits handling by two men. The floor can be finished with an attractive hard-wearing ceramic surface and the ceiling side with a textured surface. Joints on both sides can be filled in with an inorganic matrix of a compatible texture.

The same processing developed for the fire wall will be utilized for the floor ceiling. The cost to advance the product from concept to a market accepted product is discussed below.

Design and qualification for the floor/ceiling concept is straight forward. The design work remaining is optimization. The qualification requirements are presented in Appendix D. Table 62 summarizes the cost. This activity will cost from $14,930 to $26,277.

Development of the manufacturing procedure would be the same as the fire wall and Table 60 would apply. This results in a cost range of $79,600 to $144,076.

TABLE 62

DESIGN AND QUALIFICATION COST FOR FLOOR/CEILING SYSTEMS

Technical Services (Include Burden)	3,360
Mechanical Tests	3,000
Beam Bending Short Term	
Beam Bending Long Term	
E-119 Fire Test	5,000
E-84 Tunnel Test	800
Smoke	
Flame	
Materials	200
Tooling	1,000
Filing Fees	570
Travel & Support	1,000
Estimated Cost	14,930

Probable Cost = Estimated Cost $(K_{II})^{(1)}$

= 14,930(1.76)

= 26,277

---

(1) See Appendix C for K_{II}

Application of the product to the market and product acceptance would be similar to the fire wall. Therefore a cost for these activities of $325,000 would be applicable.

Therefore, the cost to get the floor/ceiling structure on the market will range from $419,530 to $495,353.

FIRE DOOR CORE

The inorganic rice hull material has potential as a fire door core. Core panels 1 1/2 inch thick faced with standard wood veneer surfaces were fabricated and fire tested utilizing ASTM-E-152 and E-119 test techniques. The formulation for the core is presented in Table 63.

TABLE 63

FIRE DOOR CORE FORMULATION

Rice Hulls 3000g @ $0.019/lb	= .126
Casting Plaster 9000g @ $0.022/lb	=.436
Prop. Binder 1200g @ $0.220/lb	= .581
Water 6600g @	=
Busan 30g @ 2.750/lb	= .182
	1.325

Wt. dry = 29 lbs Vol. = 0.74 ft^3 (2% waste)

Cost = $0.0457/lb Cost = $1.791/$ft^3$

The commercial fire door cores are now being sold to the door manufacturer for $12 per unit. These are 3ft x 6ft-8inch doors. There is a 7/8 inch wide stile and rail around the door resulting in a core of 2.33 ft^3. The waste core could be sold to a door manufacturer for $8.71 per unit. This is considerably less than that now available.

A commercial 1 hr. fire door and two waste doors were fire tested for comparison. The results are shown in Figure 37. The commercial door failed by burn through in 78 minutes. The fire test was terminated after 140 minutes on the waste core with a thin inorganic glass facing under the veneer and 130 minutes for the waste core covered only with veneer. From these results it is apparent that the waste core is far superior with an easily attainable 2 hour fire rating.

The manufacturing system proposed is a modified plaster mixer with a continuous feed onto a conveyor of molds. The facility cost should not exceed $50,000 for a production rate of 480 per day.

Design and qualification of the fire door core requires a formula selection and a test. The details are presented in Table 64. The cost will range from $9,080 to $15,981.

Development of the manufacturing procedure will result in pilot plant studies and start up and adjustment to product needs. The details are presented in Table 65. This cost will range from $82,753 to $149,782.

Application of the product to the market is well defined. The market for the cores are fire door manufacturers. The core design is common to all. Sales will be made directly to the manufacturer. The first step will be to select an interested manufacturer and supply him a core. He will construct a door with the core and then together qualify the door. These costs are covered in design and qualification. Another $10,000 should be considered for market analysis for major product acceptance.

Product acceptance for the core will be based on the performance. Since the initial production will be 150,000 units per year at least 3 door manufacturers will have to be qualified. One is qualified already which leaves two more at a cost of $9,080 each. Assuming another $10,000 for marketing services,

FIGURE ~ 37

COMPARITIVE RESULTS OF FIRE DOOR CORES
(E-119 FIRE TEST)

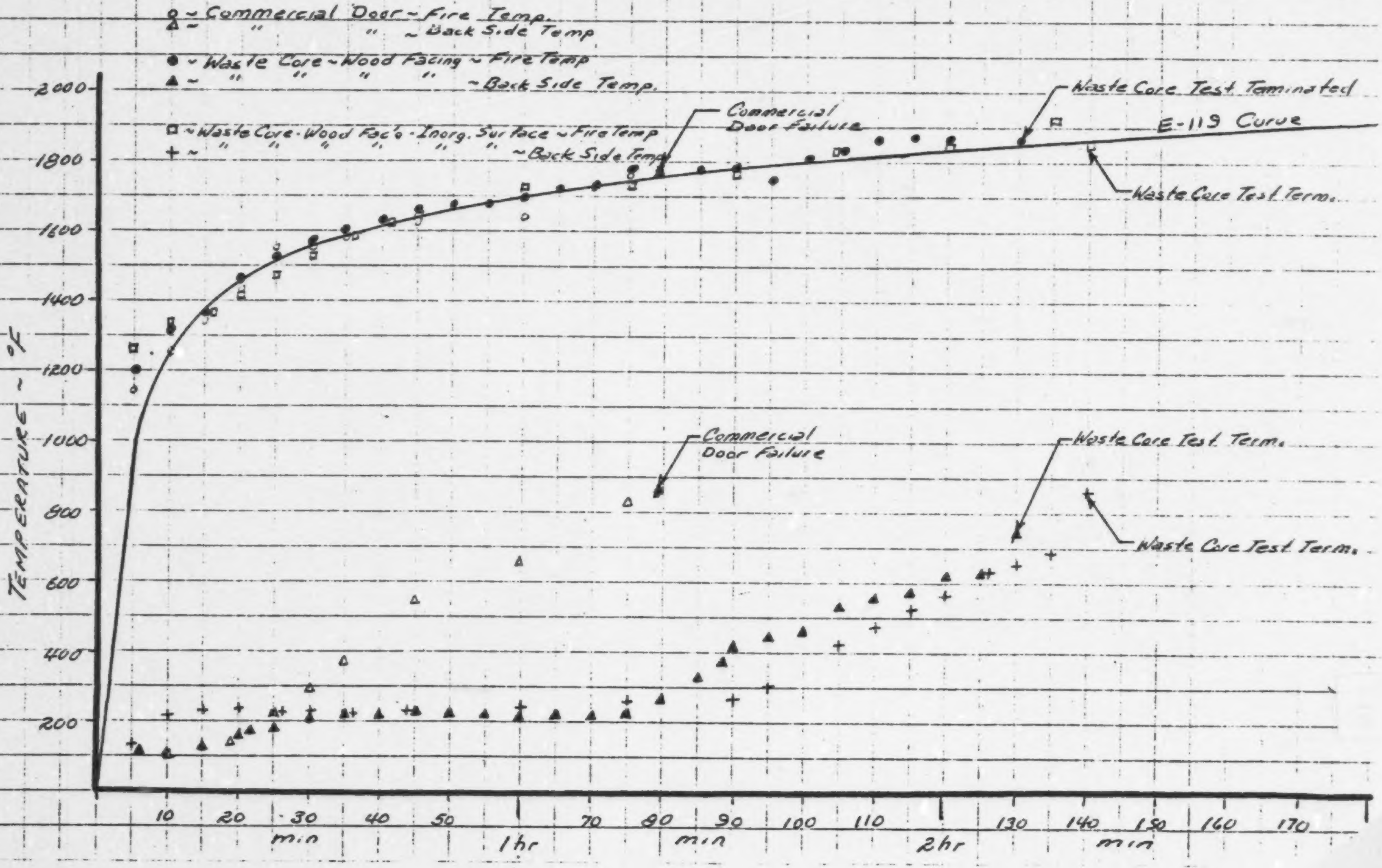


TABLE 64

DESIGN AND QUALIFICATION COST FOR THE FIRE DOOR CORE

Technical Services (Includes Burden)	3,360
E-152 Fire Door Test	4,000
Materials	50
Tooling	100
Filing Fees	570
Travel & Support	1,000
Estimated Cost	9,080

Probable Cost = Estimated Cost (K_{II}) (1)

= 9080 (1.76)

= $15,981

---

(1) See Appendix C for K_{II}

TABLE 65

DEVELOPMENT OF MANUFACTURING PROCEDURES FOR FIRE DOOR CORES

A. Pilot Plant Studies		
Technical Services (Includes Burden)	20,160	
Equipment Cost (50,000/5 yrs = 4.00/hr)	1,384	
Material Cost	1,086	
		22,630
B. Start Up and Adjustment to Product Needs		
Technical Services (Includes Burden)	20,160	
Equipment Cost (4.00/hr) Assume 75% of Product Marketable	1,038	
Material Cost - Assume 75% of Product Marketable	38,925	
		60,123
Estimated Cost		$82,753

Probable Cost = Estimated Cost (K_I) (1)

= 82,753(1.81)

= 149,782

---

(1) See Appendix C for K_I

product acceptance will cost an estimated $28,160.

In summary, to get the fire door core on the market a cost of $129,993 to $203,923, will be required. If the $12 sales price is maintained and the waste core cost is $8.71, then in one year the sale of 150,000 cores will return $493,500 over costs. This makes the core economically viable.

FRAMING MATERIAL/WOOD SUBSTITUTE

MSC housing system uses 2 x 4 wood elements for window and door framing. These elements have to be warp-free in order to fit into the system. Formulation RH-54 (Table 66) is lightweight, nailable and fire resistant. One structural application for this formulation was intended in window and door framing.

The specimens were produced by incorporating RH-54 into 0.050 Duftec channels as shown in Figures 38 and 39. The form was the Duftec channel itself supported by a wooden box to maintain alignment. The wet mixture was poured into the form and allowed to set up overnight. After this it was allowed to dry and eventually removed from the mold. It was then secondarily bonded to the channel with MSC Type "B" epoxy.

A 51" wide window panel and a 73" wide sliding glass door panel (minus window and sliding glass door frames and glazings) were constructed and then tested in axial compression in the MSC apparatus shown in Figure 40.

Figures 41 and 42 show sliding door assembly before and after load test, Figures 43 and 44 show window assembly wall before and after load test.

The window panel failed at a load of 752 lbs/linear foot while the sliding glass door panel failed at a load of 360 lbs/ft. Failure occurred when the supporting vertical legs failed in column buckling. The failing loads for the corresponding qualified ICBO window and door panels is 1800 lbs. per linear foot for each.

TABLE 66

WOOD SUBSTITUTE FORMULATION RH-54

100 parts	Rice Hulls
15 parts	1" Long Fiberglass Strands
40 parts	MSC Proprietary Binder
240 parts	Casting Plaster
60 parts	Gypsum Plaster
225 parts	Water
.5 parts	Vancide PA Germicide

(All parts by Weight)

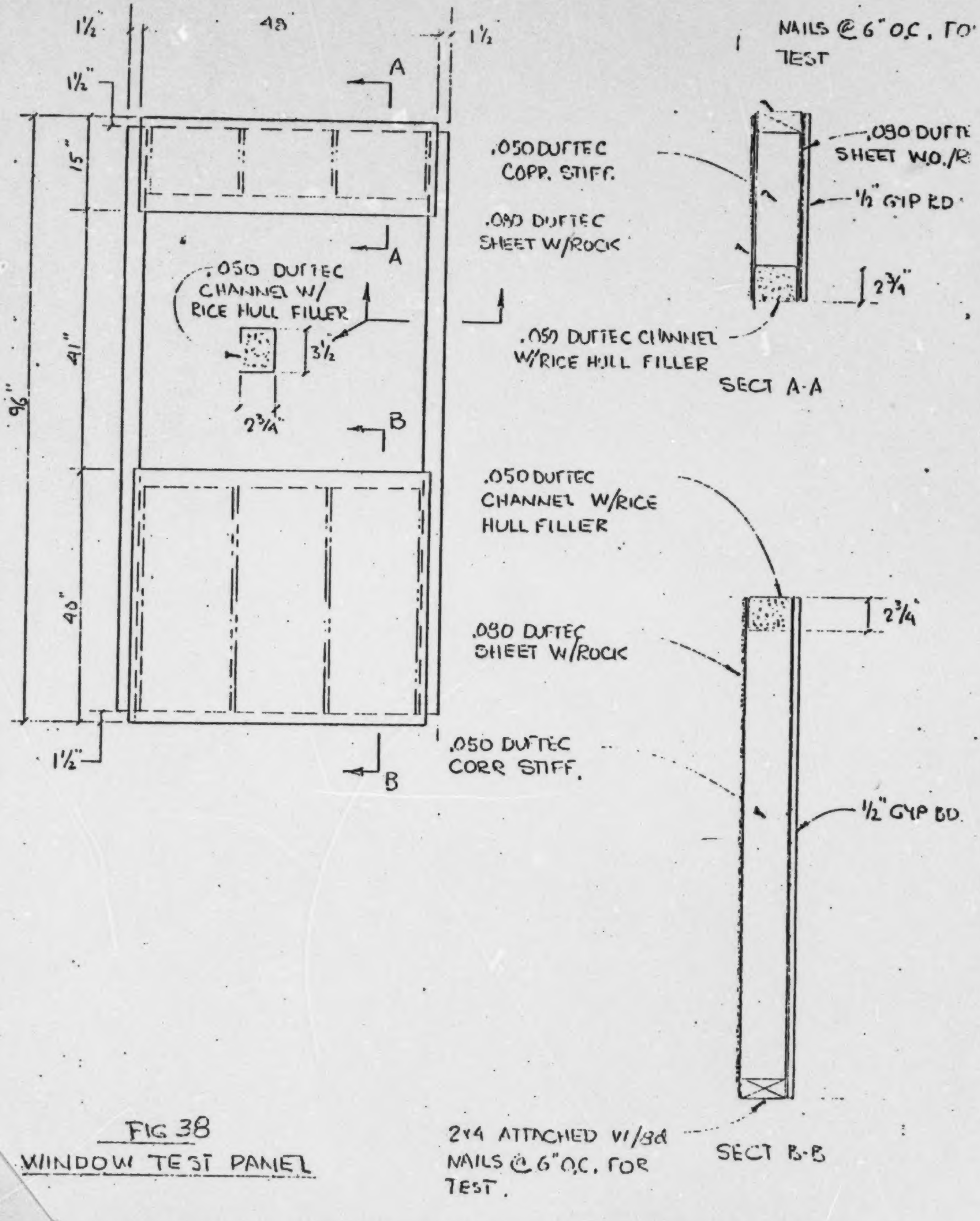

1½"
48"
1½
1½"
A
A
15"
41"
96"
48"
1½"
.050 DUFTEC CHANNEL W/ RICE HULL FILLER
3½
2¾"
B
B
NAILS @ 6" O.C. FO
TEST
.050 DUFTEC CORR. STIFF.
.090 DUFTE SHEET W.O./R
½" GYP BD
.090 DUFTEC SHEET W/ROCK
2¾"
.050 DUFTEC CHANNEL W/RICE HULL FILLER
SECT A-A
.050 DUFTEC CHANNEL W/RICE HULL FILLER
2¾"
.090 DUFTEC SHEET W/ROCK
.050 DUFTEC CORR STIFF.
½" GYP BD.
2x4 ATTACHED W/8d NAILS @ 6" O.C. FOR TEST.
SECT B-B

FIG 38

WINDOW TEST PANEL

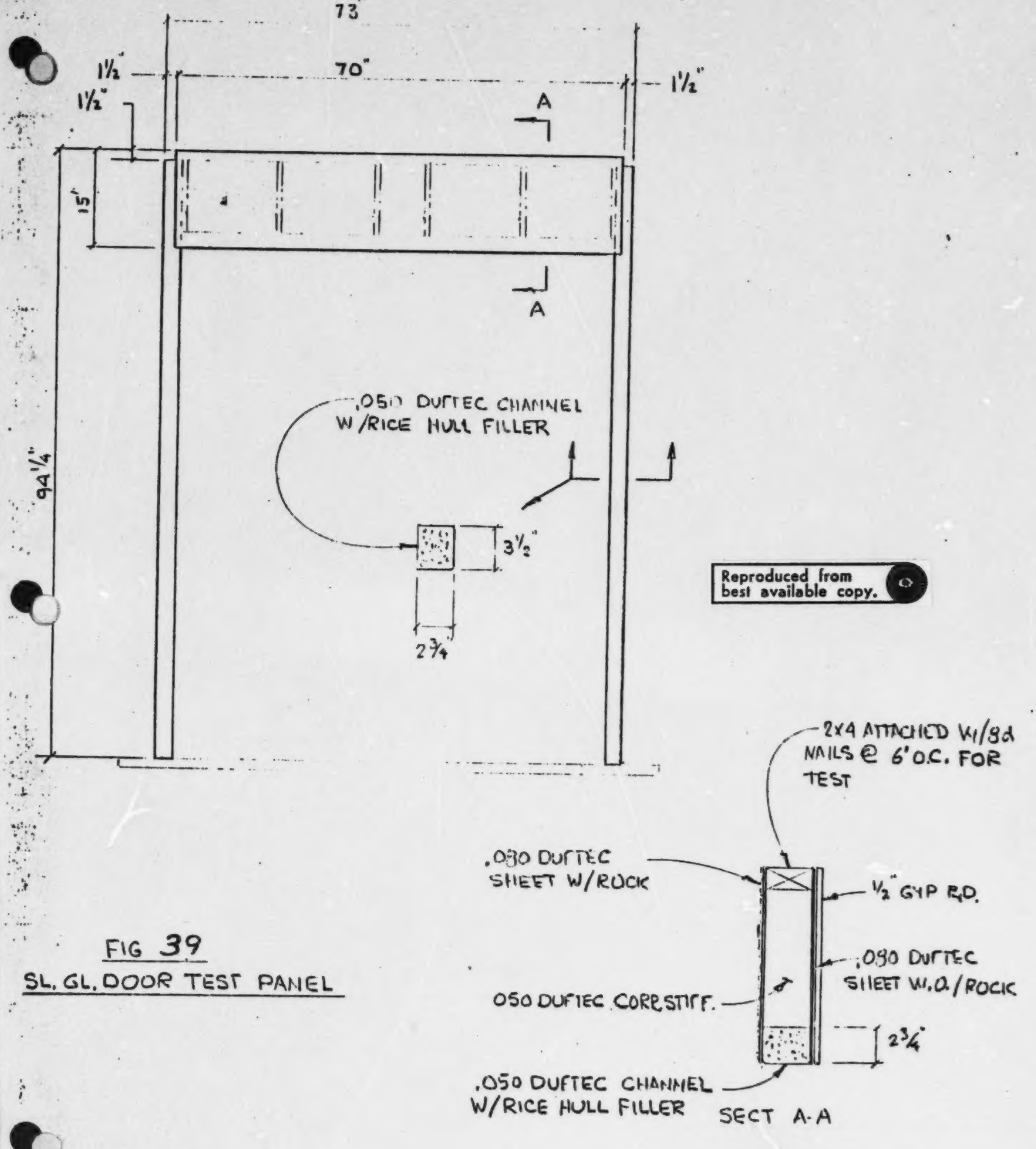
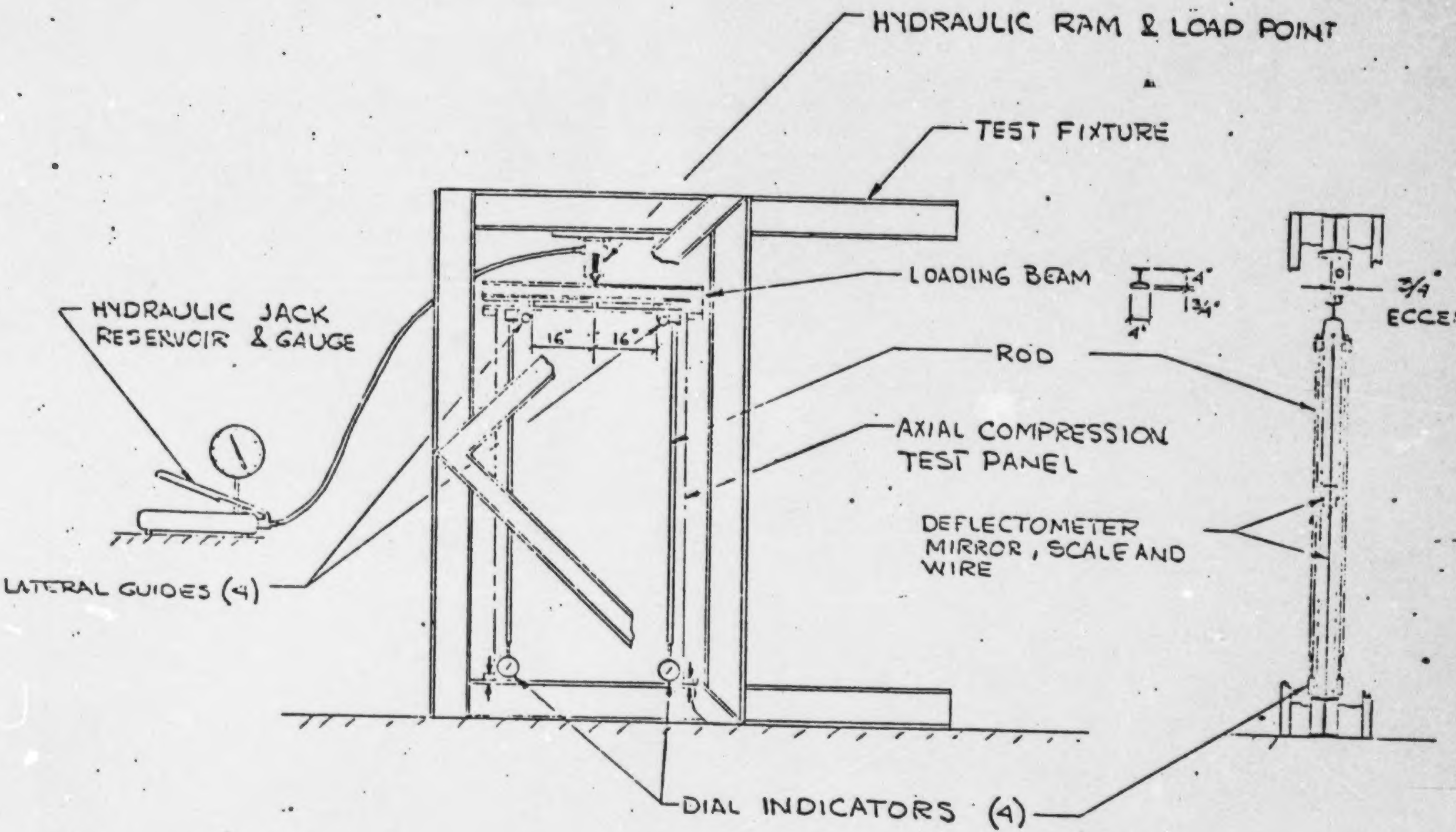

73"
1½"
70"
1½"
1½"
A
15"
A
94¼"
.050 DUFTEC CHANNEL W/RICE HULL FILLER
3½"
2¾
2X4 ATTACHED W/8d NAILS @ 6'O.C. FOR TEST
.080 DUFTEC SHEET W/ROCK
½" GYP BD.
.080 DUFTEC SHEET W.O./ROCK
050 DUFTEC CORR STIFF.
2¾"
.050 DUFTEC CHANNEL W/RICE HULL FILLER
SECT A-A

FIG 39
SL. GL. DOOR TEST PANEL

Reproduced from best available copy.


HYDRAULIC RAM & LOAD POINT
TEST FIXTURE
LOADING BEAM
4"
1¾"
4"
¾"
ECCE
HYDRAULIC JACK RESERVOIR & GAUGE
16"
16"
ROD
AXIAL COMPRESSION TEST PANEL
DEFLECTOMETER MIRROR, SCALE AND WIRE
LATERAL GUIDES (4)
DIAL INDICATORS (4)

MATERIAL SYSTEMS CORP
PANEL AXIAL COMPRESSION TEST SET

FIG 40

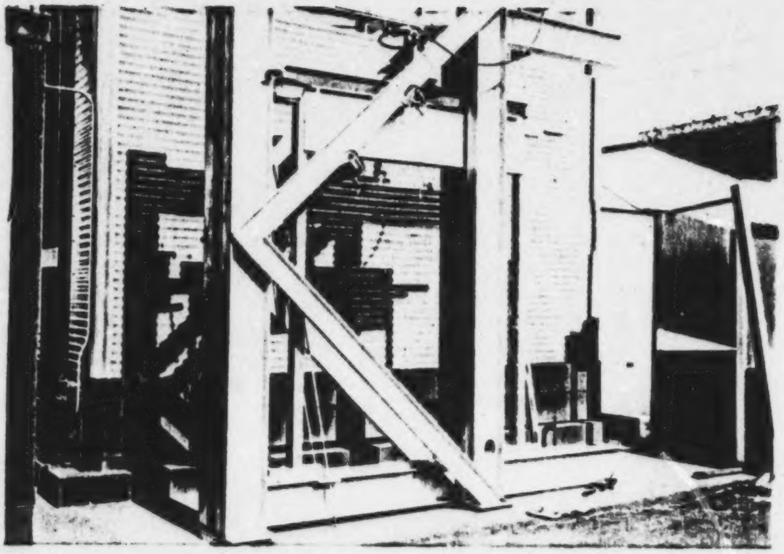


Fig. 41 Door Assembly in Test Fixture Showing Installation

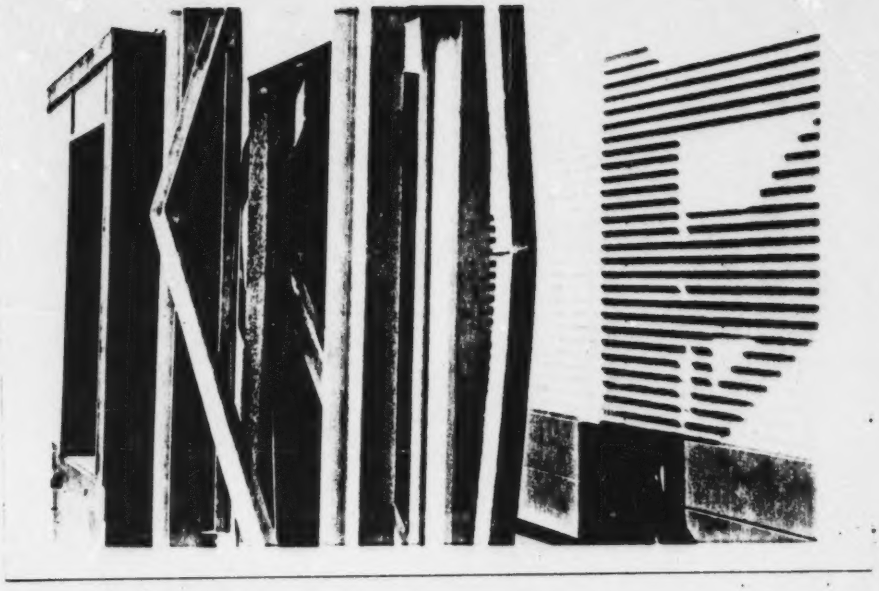


Fig. 42 Door Assembly After Axial Load Test.
Failure Shown in Buckling

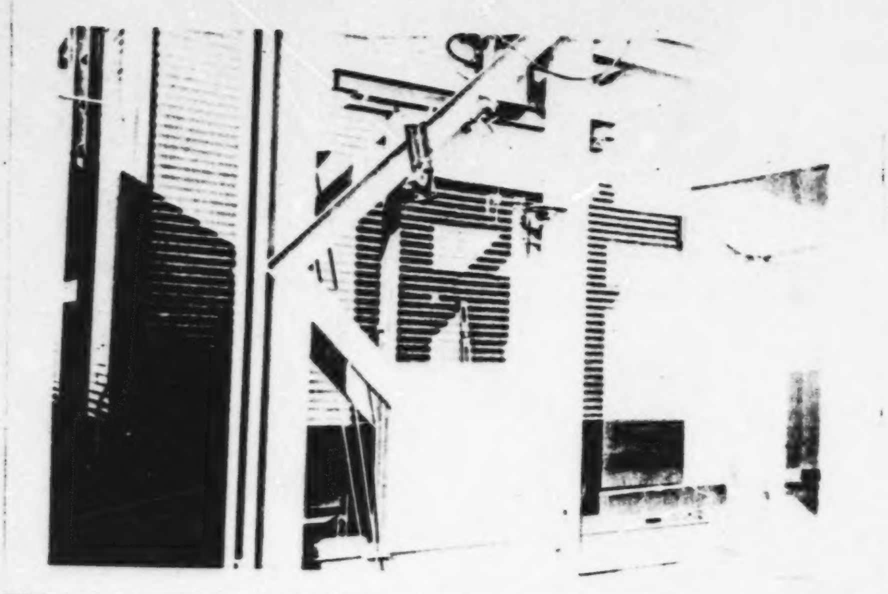


Fig. 43 Window Assembly In Test Fixture For Axial Loading.

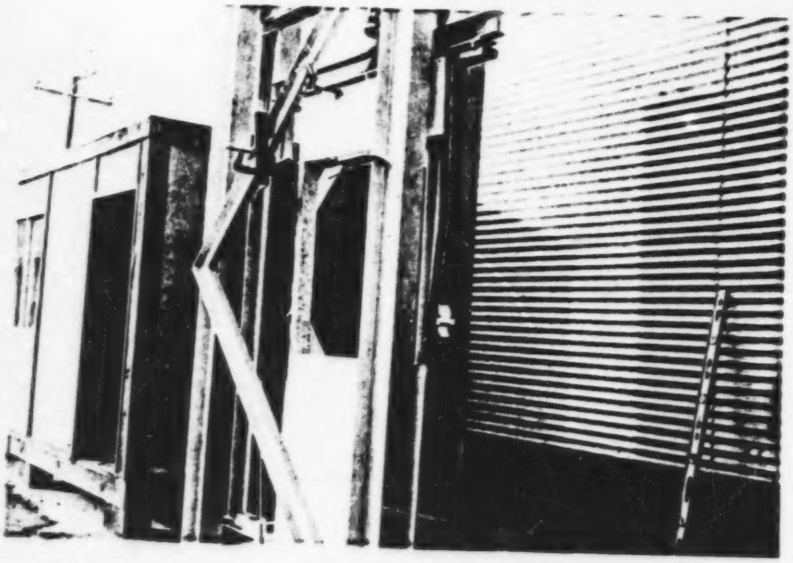


Fig. 44 Window Assembly After Axial Load Test Failure Shown In Buckling.

As previously noted, both specimens were tested to failure. The mode of failure in both cases was column buckling of the vertical rice hull filled Duftec channels at relatively low load levels (1600 pounds axial load on the column for the window and 1100 pound axial load on the column for the sliding glass door.)

Failure in both cases was preceded by considerable bidirectional lateral deflection of the column followed by a separation of the filler and channel bondline at the open edge. Considerable local bulging of the laminate occurred in this area followed by rupture and failure. See Figures 42 and 44.

It was noted that the channel edge was notched slightly on the window column at the point of failure and the rice hull mixture was fractured at the point of failure in the sliding glass door column. Both of these phenomena were present in the specimens as delivered to the test facility.

A study of the header deflection data shows that the header panels themselves remained relatively planar throughout the tests thus indicating fairly low stress levels in the rice hull filled channels service as caps. The overall deflections however reveal a certain "springiness" to the header edge attachments not experienced in the ICBO tested panels.

It becomes apparent that the rice hull filled Duftec vertical column members are not equivalent to two 2 x 4 members used in the ICBO approved system insofar as axial loading is concerned.

It is highly probable that they would not be able to withstand the required 15 PSF transverse load imposed by wind. This would amount to approximately 30 lb/ft on the window column and 45 lb/ft on the door.

In addition, ICBO imposes a combined axial and transverse load on such members either one of which would fail the column at less than acceptable design allowable.

The Duftec having an apparently higher modulus than the rice hull filler appears to act independently both under axial compression and shear conditions. This effect conceivably leads to the early separation of one from the other thus precipitating premature failure of the column.

The material cost of a 2" x 4" of RH-54 would be 0.10 per foot resulting in a $0.32 per retail cost which is approximately twice that for commercial lumber. Since the product exhibits no significant properties, exhibits dimensional stability, no further consideration is warranted.

CEILING PANELS

Rice hull formulation RH-21 (Table 37) was selected for ceiling panel product development. The design concept used a skin of gypsum plaster which was cast into a mold. A glass surfacing-mat (10 mils) was laid on as reinforcement and a retainer for the rice hulls. The mix was immediately applied and all dried together; if the plaster skin was already hard, the total material could be dried in a micro-wave oven in a matter of minutes. (See Figure 45)

The panel was subjected to a 1600°F propane torch test. The comparative results with commercial products are presented in Table 67. The waste product performed much better than the commercial ones.

There are at least 10 major manufacturers of ceiling tiles and panels offering collectively at least 239 various styles and specialty products. The product sale price ranges from $0.15 per square foot to $0.39 per square. Certain specialty panels range from $0.455 to $9.00 per square foot.

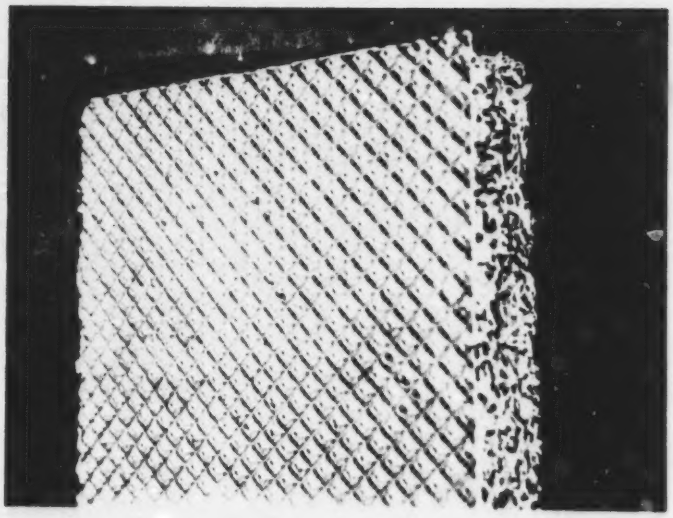


Figure 45 Integral Skin-Insulation Ceiling-Panels.

TABLE 67

COMPARATIVE PROPANE TORCH TEST

	MSC	Armstrong Fashiontone	Celotex Safetone	Celotex Protectone	Owens Corning Fissure
Panel Thickness	.560	.595	.556	.582	.580
Time to reach 380°F	6 min - 30 sec.	2 min - 45 secs	2 min - 45 secs	3 min - 45 secs.	1 min - 15 secs
Equilibrium Temp.	1180°F	NOT TESTED	NOT TESTED	1430°F	1430°F
Time to achieve Equilibrium Temp.	25 min	NOT TESTED	NOT TESTED	7.5 min	3 min
Flame	None	Surface Flash	Surface Flash	Surface Flash	-----
Smoke	None	Some	Some	Some	Some
Appearance	Severe Crack'g	Char	Char	Slight Cracking Char	Char
Cost	.102	–	–	–	–
Sale Price	.328	.169	.165	.195	.160

Panels that generate no smoke sell from $0.185 to $0.455 per square foot. The only price available on a 0 flame spread product is 0.20 to 0.30 per square foot but these generate smoke. No price is available on 0 flame spread 0 smoke. The only such product offered is an aluminum clad vinyl coated gypsum or mineral board offered by Acoustiflex.

The weight of the panels range from 0.75 lbs per square foot to 2.38 lbs per square foot.

This data is summarized in Table 1 of Appendix H.

The flame spread and smoke numbers are based on ASTM-E-84-70. The validity of this test is now in question by the FTC law suits and has always been questioned by NBS.

The structural fire rating for a floor-ceiling combination is a function of the structural design rather than the acoustical ceiling panel utilized. Nearly all producers recommend the use of an Underwriters Lab design which is applicable to all panels. (See Appendix I) The contribution of the panel is unknown.

The ceiling panel market appears to be a very specialist oriented one and a competitive one. The market area for this product would probably be in the fire rated application. The waste ceiling would possibly provide an additional 1/2 hour to 1 hour to any of the ceiling designs in Appendix I. However, the fact that this product would be in the upper cost range, and the fact that there exists many acceptable products already on the market, it is considered advisable not to persue this product line further.

PRODUCT DERIVATIVES FROM THE PARTITION WALL

There are a variety of products that can be produced from the facility utilized to produce the fire rated partition wall or floor/ceiling system.

These products are less demanding functionally and therefore conventional solutions can be resolved at a cost that makes the waste product less attractive although viable. These are discussed below.

FLOOR SYSTEM

This would be a variation of the floor/ceiling concept without the ceiling panel. This is shown in Figure 46. The cost is 53% of standard wood construction and 74% of a concrete slab.

INTERIOR WALL PANEL

This would be a variation of the 2-hour fire wall. The center rib would be removed and the surfaces reduced to 3/8 inch thickness. This is shown in Figure 47. The cost is 76% of that of a standard 2" x4" stud dry wall construction.

ROOF SYSTEM

The roof panel would require an impermeable seal as any standard roof requires. It is a variation of the floor concept with shorter length stiffness. This is shown in Figure 48. The cost is 69% of that of a standard wood construction.

CEILING SYSTEM

This is a self-supporting ceiling system and is shown in Figure 49. The cost is 69% of a standard 2" x 4" dry wall ceiling construction.

All of the above can be produced as pre-finished components and all are fire resistant, non-smoke generating products.

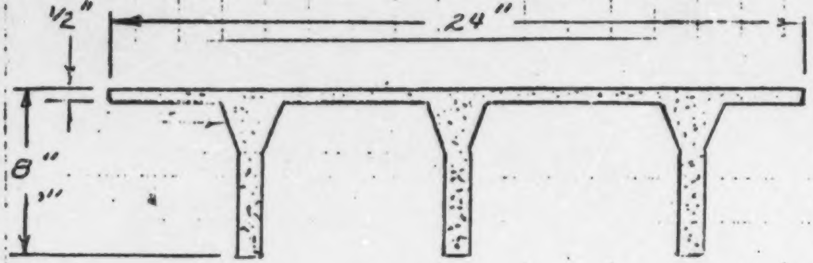


FIGURE 46

WASTE FLOOR CONCEPT

MAT'LS & LABOR $/FT²	
Waste Concept	-0.619
Std Concept (Wood)	-1.150
Std Concept (Concrete Slab)	-0.830

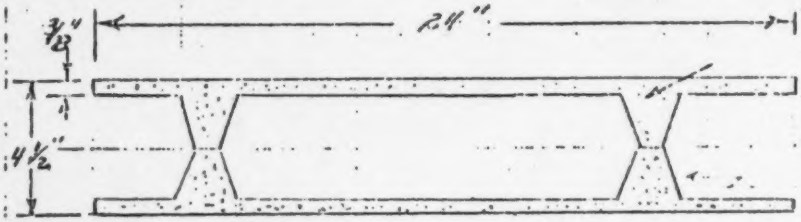


FIGURE 47

INTERIOR WALL PANEL

Waste Concept	-0.70
Std Concept	-0.92

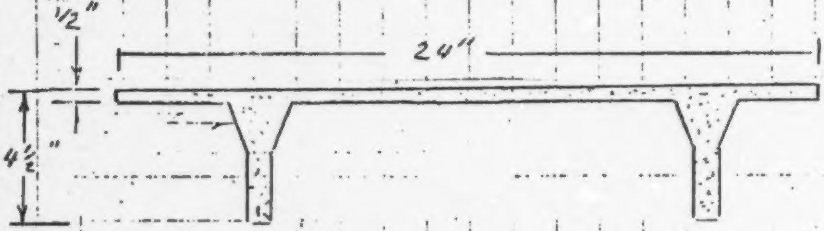


FIGURE 48

ROOF WASTE CONCEPT

Waste Concept	-0.55
Std. Concept	-0.80

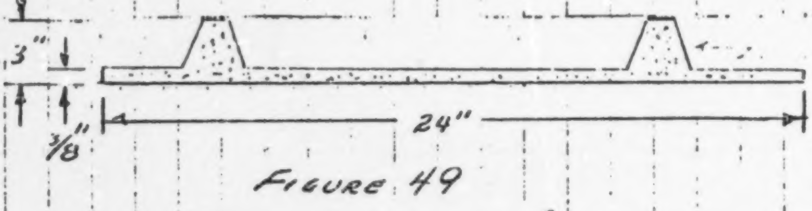


FIGURE 49

CEILING WASTE CONCEPT

Waste Concept	-0.450
Std Concept	-0.652

APPENDIX A

QUANTATIVE DETERMINATION OF FURFURAL

APPENDIX A

Quantitative Determination of Furfural[3]

Preparation of Reagents

0.1N Iodine Solution

Twelve and six tenths grams of Iodine (purified crystals) and 25g of potassium iodide (Reagent A.C.S.) were dissolved in distilled water. The solution was made up to 1 liter in a volumetric bottle and magnetically stirred overnight to assure complete solution of the iodine.

0.1N Sodium Bisulfite Solution

Five and two tenths grams of sodium bisulfite (Baker analyzed reagent) was dissolved in distilled water and made up to one liter in a volumetric bottle.

0.1N Sodium Thiosulfate (standard solution)

Prestandardized certified Fischer Scientific Company was used.

Starch Solution

Commercial (food grade) corn starch was dissolved in water, and boiled for ten minutes then diluted to give free flowing solution.

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[3] A. P. Dunlop and F. Trimble Ind. Eng. Chem. Anal. Ed. 11 602 (1939)

Accuracy Determination

1. Iodine solution was standardized with Sodium thiosulfate solution (factor= 0.988)
2. Commercial furfural was used to prepare a 5% solution by using 10.03g of this solution weighed into a volumetric bottle, and made up to 100 ml. Five ml of this solution was transferred to a flask, and 25 ml of 0.1N sodium bisulfite added, mixed and allowed to stand for 15 minutes; 25 ml of the same sodium bisulfite solution were put in a second flask, and left standing for 15 minutes. To both solutions was added 3-4 drops of starch solution, and titrated with the iodine solution!

Bisulfite Solution: 25, 9, 26.0, 26.0 = 26.0
Furfural Solution: 20.5, 20.5, 20.5 = 20.5

c (furfural concentration)

$$\frac{1.07\ (26.0 - 20.5)\ 0.0048 \times 20 \times 100 \times 0.988}{10.03} = 5.56\%$$

The results show a 10% deviation from the true concentration.

Notes About Bisulfite Method

1. Samples taken from the hydrolysis solution were filtered to remove any solids. After accurately weighing, one drop of phenolphthalein was added, the solution neutralized with sodium hydroxide solution and water added to make up to 100 ml.

2. The authors claim that the bisulfite solution must be titrated with each sample. This proved to be true, because the concentration of bisulphite changed rapidly.

Method of Calculatings Furfural Yield

1. Rice hulls: hydrolysis mixtures is composed of :

   30 g rice hulls
   115 ml water
   3 ml hydrochloric acid.

   it is assumed:

   1. that rice hulls contain negligible amount of water.
   2. that no liquid has evaporated during reflux.

   Sample of calculation after 20 hour reflux =

   sodium bisulfite: 26.25 ml

   Sample: 25.30; 25.00 = 25.15

   Concentration of furfural:

$$c = \frac{1.055x(26.25-25.15)x0.0048x20x100x0.988}{10.19} = 1.05$$

   amount of furfural: $cxv = \frac{1.05x118}{100} = 1.24g$

   yield of furfural, based on rice hulls weight = $\frac{1.24}{30} x 100 = 4.43\%$

2. Corn Cobs:

Hydrolysis mixture is composed of:

120 g fresh feeled and ground corn cobs.
200 ml water
12 ml hydrochloric acid.

notes: it was found by experiment that ground corn cobs lose 60% of their weight (which is assumed to be water).

it is assumed that no liquid is evaporated during reflux. The yield of furfural can be calculated in three different methods depending on the following considerations:

a. yield based on weight of fresh ground (wet) corn cobs.

sample:

sodium bisulfite: 20.25 ml
sample: 24.4 : 24, 25 = 24.3

concentration of furfural:

$$c = \frac{1.06x(26.25-24.3)x0.0048x20x100x0.988}{10.19} = 1.85\%$$

If the volume of solution is just 212 ml the amount of furfural is:

$$\frac{1.85x212}{100} = 3.92g$$

$$\text{yield of furfural} = \frac{3.92}{120} x\ 100 = 3.26\%$$

b. yield based on weight of dry corn cobs (water included) based on dry cobs, we have from 120g fresh corn cobs, 98g solids and 72 ml water. We assume here that these water take part in the overall solution and the furfural produced is evenly dispersed. Then:

Amount of furfural in 284 ml solution is:

$$\frac{1.85x284}{100} = 5.25g$$

yield of furfural:

$$\frac{5.25}{48} \times 100 = 10.93\%$$

d. yield based on dry corn cobs
(water excluded):

In this case we just ignore the water included in the cobs but calculate on the basis of 40g dry cobs. So, amount of furfural remains 3.92 g.

yield of furfural:

$$\frac{3.92}{48} \times 100 = 8.16\%$$

APPENDIX B

MATERIAL SYSTEMS CORP. ETR No. 80

ECONOMIC COMPARISON OF WASTE PROCESS PARTICLE BOARD WITH CONVENTIONAL PROCESS PARTICLE BOARD

29 August 1975

Prepared by: Bud Duft
Bud L. Duft
President

PARTICLE BOARD MARKET

Figure 1 presents the consumption of particle board thru 1969 with a projection thru 1970. As can be seen, furniture represents more than 50% of the consumption. Because of the furniture consumption the major market is in the south where the major furniture manufacturers are located. Figure 2 presents the regional distribution of markets thru 1969 with a projection thru 1975. Figure 3 shows the relative saturation of the particle board market.

ECONOMICS OF WOOD PARTICLE BOARD MANUFACTURE

There are three major factors which influence the profitability of a particle board operation.

1. Wood costs and raw material type.
2. Geographic location of a plant in relation to the markets (out bound freight costs)
3. Plant size.

Assuming all plants are competently managed all other costs are the same. The comparison of wood costs delivered to a plant does not provide an accurate study. A true comparison must include preparing the wood ready to enter the blender or point of impregnation. Table 1 presents a comparison of these costs. Therefore, the wood cost is extremely important in that a plant utilizing shavings can pay considerable more freight to a further market than can a plant utilizing wood pulp. This is the reason Western plants can compete with the Southern plants for a Southern market. The distribution of the United States particle board capacity is shown in Table 2.

In order to compare the effects of plants using different raw wood materials and the effects of plant size, the following discussion is excerpted from Reference 1.

A rough estimate for three types of plants is included in Table 3. The breakdown of equipment costs include storage and unloading, milling and drying, blending and forming, the pressline and the finishing line equipment. The storage and unloading, milling and drying and auxiliary equipment costs are higher when working with chips or logs.

Freight and installation costs are again higher for plants based on chips or logs because more equipment is needed for operation. It is found that the plant that uses logs is considerably more expensive than either of the plants using shavings and pulp chips.

The figure for engineering contingencies and other pre-start up expenses is generally estimated to be about 20%. Therefore, a total plant cost is estimated at $4 million, $4.5 million and almost $5 million respectively for plants based on shavings, pulp chips, and logs. This is an example for a plant capable of producing about 50 to 55 million sq. ft. a year or, in other terms, one that would produce over 200 tons of board a day.

Now examine the manufacturing costs for these three plants (Table 4). In this example, assume that shavings are purchased at $7 a ton, chips at $14 a ton, and logs at $14 a ton. It should be noted that in most locations and especially in the Southern pine region, it is very difficult to get chips for as little as $14 per dry ton.

Eight and one-half percent resin is being used in shavings board and 8% in the boards made with furnish from pulp chips or logs. Comparatively, these figures should be appropriate. One percent of wax is incorporated into all boards.

In the raw material costs alone, there is quite a difference in cost ranging from $38/M sq. ft to $48.10/M sq. ft for boards based on logs.

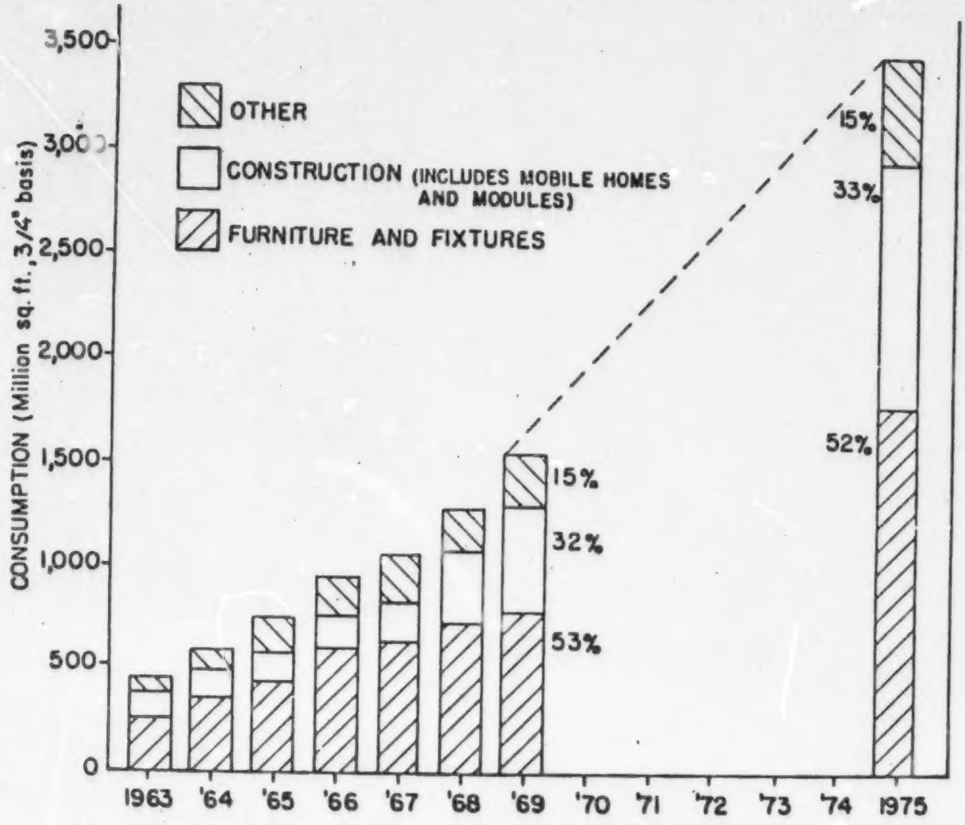


Figure 1. U. S. Consumption of Particleboard from 1963-75.

Economics of Particleboard Manufacture Revisited or An Assessment
the Industry in 1970 - Peter Vajda

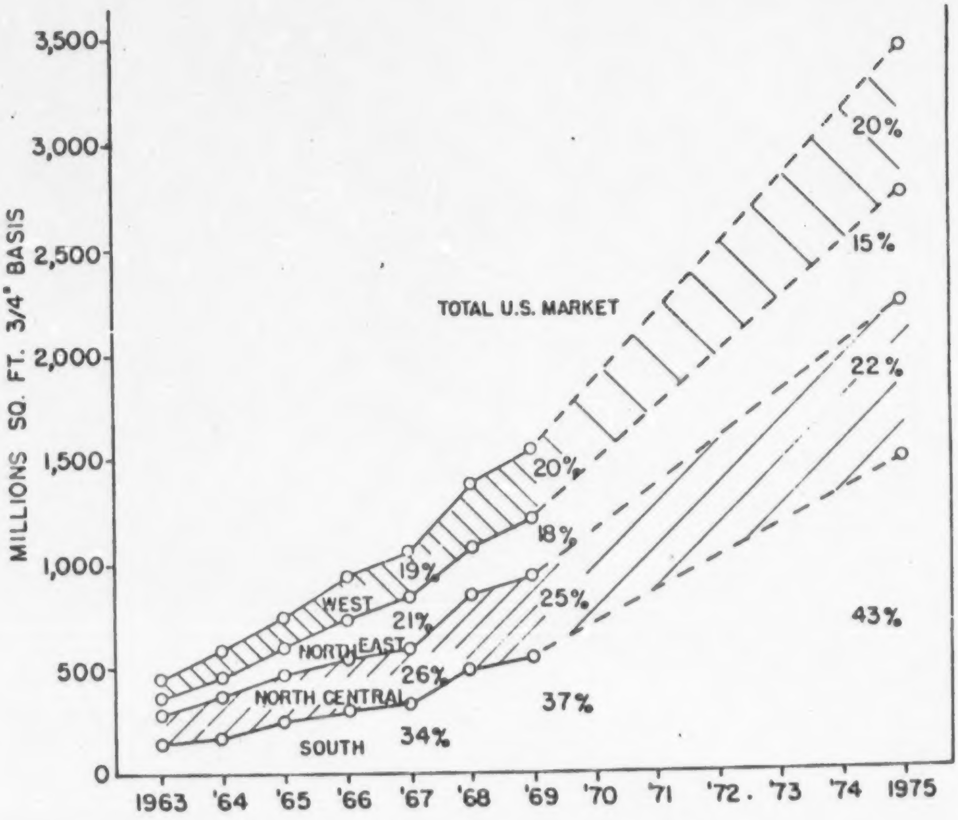


Figure 2. Regional Distribution of U. S. Particleboard Markets from 1963-75.

Economics of Particle board Manufacture Revisited or An Assessme
the Industry in 1970 - Peter Vajda.

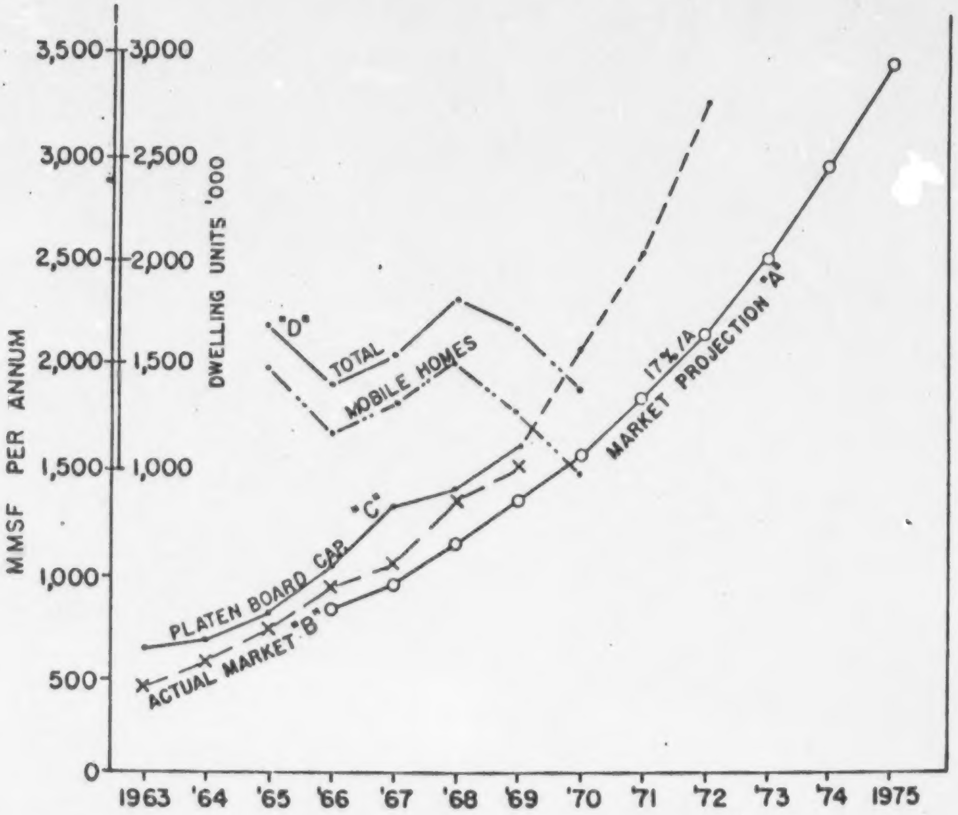


Figure 3. Comparison of U. S. Particleboard Capacity and Markets.

he Economics of Particleboard Manufacture Revisited or AN ASSESS-
ent of the Industry in 1970 - Peter Vajda

Table 1: COMPARISON OF PROCESSED WOOD COST

	Dry Shavings	Pulpwood
Wood cost (Dollars/ton)	5	17
Processing Costs	2	9
Wood Furnish Cost	7	26

Table 2: DISTRIBUTION OF U.S. PARTICLEBOARD CAPACITY

Regional Distribution

	West		South		North		Total
Year	MMsf	%	MMsf	%	MMsf	%	MMsf
1967	800	59	400	33	130	8	1,300
1969	850	52	620	39	170	9	1,640
1970	1,080	49	920	42	200	9	2,200
1972	1,620	47.5	1,570	46.5	200	6	3,390

Distribution per Plant Size

	Total Capacity	Over 60 MMsf/annum		Under 60 MMsf/annum	
Year	MMsf	MMsf	%	MMsf	%
1967	1,300	540	39	760	61
1969	1,640	860	51	780	49
1972	3,390	2,550	75	840	25

Table 3. Comparison of Plant Costs Using Three Different Raw Materials for Furnish.

	Dry Shavings	Pulp Chips	Logs
Plant Construction Costs			
Storage & Unloading	$ 120,000	$ 210,000	$ 250,000
Milling & Drying	190,000	340,000	540,000
Blending & Forming	490,000	490,000	490,000
Press Line	1,020,000	1,020,000	1,020,000
Finishing Section	350,000	350,000	350,000
Auxiliary Equipment	270,000	310,000	380,000
Total Equipment Costs	2,440,000	2,720,000	3,030,000
Duty & Freight	120,000	150,000	180,000
Installation Costs	300,000	330,000	360,000
Total, Equipment Installed	2,860,000	3,200,000	3,570,000
Buildings & Structures	500,000	540,000	580,000
Total, Equipment & Plant	3,360,000	3,740,000	4,150,000
Engineering Contingency, & other pre-start-up expenses (about 20%)	640,000	740,000	800,000
TOTAL PLANT COSTS	4,000,000	4,580,000	4,950,000

Table 4: Comparison of Manufacturing Costs for Plants Based on Three Different Raw Materials for Furnish

	Dry Shavings		Pulp Chips	Logs
Manufacturing Costs	$/Msf 3/4 in.		$/Msf 3/4 in.	$/Msf 3/4 in.
Dry Shavings @ 7/od ton	$10.40		-	-
Wet Chips @ $14/od ton	-		$20.80	-
Logs @ $14/od ton	-		-	$22.00
Resin - 8.5%	24.00	(29.00)	-	-
8.0%	-		22.50	22.50
Wax - 1.0%	3.60		3.60	3.60
Total Raw Materials	38.00	(43.00)	46.90	48.10
Power	1.90	*	2.50	3.70
Fuel	1.10		1.90	2.00
Labor	10.20		11.50	14.00
Maintenance & Operating Supplies	5.00		6.30	7.40
Total Direct Costs	56.20	(61.20)	69.10	75.20
Administrative Salaries & Expenses	3.50	(3.81)	3.50	3.50
Insurance & Taxes (1%)	.70	(.70)	.80	.90
Operating Contingency (5%)	3.00	(3.29)	3.50	3.80
TOTAL MANUFACTURING COSTS	63.40	(69.00)	76.90	83.40

(Up dated with '75 resin costs)
Board Density = 30 lbs/ft^3

* This may change with resin to maintain a 60% ratio between raw material and manufacturing costs.

Looking further, notice the breakdown of total costs. If anything, the labor requirement for log handling is under-estimated. In most such plants actual labor costs are 10 - 30% higher. In addition, the maintenance costs for this type of equipment can also be much higher. The figures for administractive salaries, insurance and taxes, as well as an operating contingency are arbitrary, but are considered to be reasonable.

The tables show that there is a $20 difference per M sq. ft. in the operating costs between a plant based on dry shavings and one based on logs. It costs $63.40, $76.90 and $83.40 to manufacture a M sq. ft. of board for comparable sized plants based on dry shavings, pulp chips and logs.

A potential investor is naturally interested in the return on investment. In order to calculate the earnings potential of these plants, assume a product price structure or a net-to-mill recovery level for the product.

Obviously the plant is going to produce products in various thicknesses, densities and for a number of applications. The prices of such products depend on the customers, market areas and various other factors. The product mix manufactured at any plnat will obviously have a strong influence on the average recovery.

Rather than going through the complicated assumptions and calculations regarding price structures and product mixes, it will be more simple for the purposes of this discussion to assume an average net-to-mill recovery 3/4 in. board basis, since all the manufacturing costs shown in Table 4 are also related to a product mix calcualted on 3/4 in. board basis.

By experience state that the average net-to-mill recovery for a plant making a shavings board, which is located in the Southern States area, is approximately $106/Msf 3/4 in. basis. For the purposes of discussion, also assume that a price of $2 more, or $108/Msf for boards made out of chips, and $114/Msf for boards made out of round wood can be achieved. Also assume in all cases that the plant is operating with a 5% reject factor (covering the cost of outright rejects, as well as down-grade sold below list price); consequently, sales figures are assumed to be 5% less than production output figures.

Table 5 summarized the comparative earnings and returns for the three plants. It can be seen that whereas the plant manufacturing board out of shavings shows a 21.2% return after taxes and the plants manufacturing board out of pulp chips and logs show returns of 11.8% and 9.2% respectively.

One can conclude from these figures that the only way to equalize returns on investments is to charge higher prices for the products of the plants using pulp chips and logs. There is some cause to believe that this could be accomplished, since boards produced out of pulp chips and logs are of higher quality, at least on a laboratory standard basis, especially due to their higher strength properties and better machinability characteristics. Unfortunately, it has been found impossible to sell such products in the market place at adequate prices and the price differentials shown in Table 5 are about as much as can be reasonably expected. Consequently, the plants using shavings as raw material promise to be better investments than plants using chips or logs. An investigation of the earnings record of the industry over the past five years most certainly bears out this statement.

Table 5. Comparison of Returns on Investment for Plants Based on Three Different Raw Materials for Furnish.

	Dry Shavings	Pulp Chips	Logs
Net-to-mill recovery (per Msf)	$ 106	$ 108	$ 114
Sales	5,640,000	5,750,000	6,060,000
Cost of Production	3,540,000	4,280,000	4,670,000
Gross Profit	2,100,000	1,470,000	1,390,000
Depreciation (10% straight line)	400,000	460,000	490,000
Profit before Taxes	1,700,000	1,010,000	900,000
Allowance for Taxes	850,000	505,000	450,000
Net Profit	850,000	505,000	450,000
Return on Plant Investment	21.2%	11.8%	9.2%

Comparative economics of different sized plants using the same raw material: For the sake of simplicity in comparing the economics of different sized plants, assume that the plants are using the same raw material at the same cost. Table 6 provides the comparative capital costs of plants designed to produce 20 MM, 33 MM, and 56 MM sq. ft/annum 3/4 in. board respectively, all using dry shavings as raw material. For the sake of comparison, investment costs per daily ton output are shown. As should be expected, investment costs per daily output decrease as the plant size increases.

Naturally these figures are not absolutely correct for every location. For comparison purposes, however, they should be appropriate. In some cases, it might be possible to build a 20 million sq. ft. a year plant for less than $2 million. However, certain penalties would have to be incurred that would make the operation difficult in the future.

Table 6. Comparison of Plant Costs for Three Different Sized Plants Producing Board from Dry Planer Shavings.

	Plant A	Plant B	Plant C
Plant Output: (Msf 3/4 in. per 330-day year)	20,000	33,000	56,000
Average Daily Output: Msf	60	100	170
Tons	75	125	210
Plant Construction Costs			
Storage & Unloading	$ 80,000	$ 100,000	$ 120,000
Milling & Drying	110,000	150,000	190,000
Blending, Forming & Pressing	680,000	1,150,000	1,510,000
Finishing Section	290,000	330,000	350,000
Auxiliary Equipment	180,000	220,000	270,000
Total Equipment Cost	1,340,000	1,950,000	2,440,000
Duty and Freight	60,000	90,000	120,000
Installation Costs	190,000	220,000	300,000
Total Equipment Installed	1,590,000	2,260,000	2,860,000
Buildings & Structures	250,000	350,000	500,000
Total, Equipment & Plant	1,840,000	2,650,000	3,360,000
Engineering Contingency & Other Pre-Start-Up Expenses (about 20%)	360,000	520,000	640,000
TOTAL PLANT COSTS	2,200,000	3,130,000	4,000,000
Investment Per Daily Ton Output	$29,300	$25,000	$19,000

Table 7. Comparison of Manufacturing Costs for Three Different Sized Plants Producing Board from Dry Planer Shavings.

	Plant A	Plant B	Plant C
Annual Output (Msf 3/4 in./A)	20,000	33,000	56,000
Manufacturing Costs			
Wood @ $7/od ton	$10.40	$10.40	$10.40
Resin	24.00	24.00	24.00
Wax	3.60	3.60	3.60
Total Raw Materials	38.00	38.00	38.00
Power	2.60	2.10	1.90
Fuel	1.50	1.30	1.10
Labor	17.50	13.00	10.20
Maintenance & Operating Supplies	6.00	5.50	5.00
Total Direct Costs	65.60	59.90	56.20
Admin. Salaries & Expenses	5.50	4.50	3.50
Insurance & Taxes	1.20	1.00	.70
Operating Contingency (5%)	3.50	3.20	3.00
TOTAL MANUFACTURING COSTS Per Msf 3/4 in.	75.80	68.60	63.40

In this comparison, all plants are identical as far as using shavings, the same resin level, the same wax level and a common pay scale. Table 7 provides information on manufacturing costs for these three plants. The larger plant pays less for power by buying it in larger blocks. Labor costs in the larger manufacturing plant are also smaller. The total direct cost per M sq. ft. of 3/4 in. board ranges from $65.60 for the small plant to $56.20 for the large plant. After the administrative costs, insurance, taxes, and operating contingencies are added, the costs range from $75.80 for the small plant to $63.40 for the large plant.

Table 8 compares the annual return on investment for these three plants. Net-to-mill recovery is assumed at $110 per Msf for the small plant to $106 per Msf for the large plant. The larger plant will have to sell in a larger market area and consequently will have higher freight costs. In spite of this, the small plant has the lowest return on investment, 8%. The intermediate plant return is 12.5% and the large plant return is 21.2% after taxes.

The return on investment at a low sales price is considered in Table 9. In this example, the net price if $80/M sq. ft. for each plant. In this case only the larger plant shows any return on the investment (4.25%).

Table 8. Comparison of the Annual Return on Investment for Three Different Sized Plants Producing Board from Dry Planer Shavings.

	Plant A	Plant B	Plant C
Plant Output (Msf 3/4 in./A)	20,000	33,000	56,000
Net-to-Mill Recovery ($/Msf)	110	108	106
Sales (5% Rejects) ($/A)	$2,090,000	$3,400,000	$5,640,000
Cost of Production ($/A)	1,520,000	2,270,000	3,540,000
Gross Profit	570,000	1,130,000	2,100,000
Depreciation	220,000	310,000	400,000
Profit before Taxes	350,000	780,000	1,700,000
Allowance for Taxes	175,000	390,000	850,000
Net Profit	175,000	390,000	850,000
Return on Plant Investment	8.0%	12.5%	21.2%
Cash Flow	395,000	700,000	1,250,000
Payout Period (years)	5.5	4.5	3.2

Table 9. Comparison of the Annual Return on Investment at Low Sales Prices for Three Different Sized Plants Producing Board from Dry Planer Shavings.

	Plant A	Plant B	Plant C
Plant Output (Msf 3/4 in./A)	20,000	33,000	56,000
Net to Mill Recovery ($/Msf)	80	80	80
Sales (5% Rejects) ($/A)	$1,520,000	$2,510,000	$4,280,000
Cost of Production ($/A)	1,540,000	2,270,000	3,540,000
Gross Profit or Loss	(20,000)	240,000	740,000
Depreciation	220,000	310,000	400,000
Profit or Loss before Taxes	(240,000)	(70,000)	340,000
Allowance for Taxes	----	----	170,000
Net Profit	----	----	170,000
Return on Plant Investment			4.25%
Cash Flow	(20,000)	240,000	570,000
Payout Period (Years)	----	13	7.1

These figures would indicate that a small plant is a poor investment. Obviously, some small plants exist, operate and some of them make a pretty good return on the investment. It can be safely stated that all such plants have some or more special conditions going for them. Either they operate on extremely low raw material cost, or sell the product to a specialized, almost, captive market, near the plant location or provide special service to selected customers, and consequently achieve unusually high net-to-mill recovery. Some of these small plants do not stop at the manufacture of particleboard, but carry the process further by manufacturing semi-finished or finished furniture components. Such components are lumber-banded board, panels cut to special end uses, particleboard overload with veneer or plastic overlays.

An examination of the successful small plants in the United States will show that in most cases all of these factors are present. Any one of these factors alone is not sufficient to make the plant competitive.

The most frequent erroneous assumption made is that a small plant selling the product in the small immediate market area will have lower freight costs and can therefore be competitive.

It is very difficult to capture 50% or more of any market area, no matter how close to the plant, as the large manufacturing firms have warehousing outlets in most of the marketing areas in the United States and it is difficult to compete with them on the basis of price alone. Consequently, a large plant because of its inherent efficiency can operate on higher wood costs and higher freight costs and still sell to a customer at a lower price. Therefore, a small plant can only be justified if all of the above mentioned factors are present and the sales connections to the few selected customers are well established. It can also be stated that it is highly unlikely that a large corporation can operate a small plant successfully, as the head office overhead of a large corporation alone would render a small volume operation uncompetitive.

ECONOMICS OF WASTE PROCESS PARTICLE BOARD MANUFACTURE

Two commercial particle board processes are shown in Figure 4. The waste process is shown in Figure 5. This process will use much of the same equipment. The rice hulls or peanut shells will be fed into a storage area from which measured amounts will be transported to the resin wash. From the resin wash, the material will go to a wet preformer. The preformed billets will then be passed through a dryer to remove excess water. The dry billets are then pressed, past treated and trimmed. Table 10 presents a summary of estimated equipment costs for a plant to 50 to 60 million square feet of panel a year. As can be seen, the waste process for particle board would cost about 78% of that of a conventional plant.

Table 11 presents a cost analysis of organic particle board. These costs can be utilized to determine the cost for a 1/2 inch 4 ft x 8 ft panel. Densities of 60 lb/ft^3 plus as tested will be compared with commercial 55 lb/ft^3 particle board.

	Rice Hulls	Peanut Shells	Wood Chips	Commercial Particle Board
1. Material Cost	0.632	0.898	0.881	1.681
2. Cost to Mfg. (1.67)(1)	1.055	1.501	1.471	2.807
3. Cost to Retailer (1.25)(2)	1.318	1.876	1.838	3.509
4. Cost at Retail (1.54)(3)	2.031	2.889	2.832	5.402

Based on this analysis the retail price of the waste process particle board would be 38% to 53% of that of commercial particle board.

It is assumed that the inflation rate on equipment costs have been 3 since 1967 and the other costs 2, then the facility would cost be approximately $9,000,000. (From Table 4 and 11). The following analysis can then be made for this process.

1. Assume the plant cost is $9 million.
2. Material costs is .007/lb (rice hulls), .011/lb (peanut shells), .010/lb (wood chip).
3. Assume sales to retailer are .048/lb (commercial particle board).
4. Generated differences are

   Rice Hulls = .041/lb

Peanut Shells = .037/lb, and

Wood Chips = .038/lb.

This assumes the plant is in the waste producing area. Transportation costs are in the sales to retailer.

5. The fixed operational costs are as follows

Labor	$561,000 per year
Maintenance & Operating Supplies	275,000 per year
Indirect Cost	429,000 per year
Depreciation	900,000 per year
	$2,165,000 per year

Per day costs = $8,326 per day

6. There is an additional 7% of material cost added to all cost of production.

7. The breakeven production rate would then be

Rice Hulls: $$\frac{\$8{,}326/\text{day}}{.041/\text{lb} - (.007/\text{lb})(0.7\ \text{cost/lb})} = 205{,}580\ \text{lbs/day}$$

Peanut Shells: $$\frac{\$8{,}326/\text{day}}{.037/\text{lb} - (.011\ \text{lb})(.07\ \text{cost/lb})} = 229{,}809\ \text{lbs/day}$$

Wood Chips: $$\frac{\$8326/\text{day}}{.038/\text{lb} - (.010\ \text{lb})(.07\ \text{cost/lb})} = 223{,}217\ \text{lbs/day}$$

8. Assume full production

The facility costs presented here are based on 200 tons per day of 30 lb/ft^3 board. The plant is volume limited not density limited. Therefore the more dense panels of 60lb/ft^3 will permit a production of 400 tons per day. Then the profit is as follows:

Rice Hulls: 800,000 lbs (.041) = $32,800/day Generated
- 8,326/day Fixed Cost
- 392/day Variable Cost

$24,082/day Profit

Peanut Shells: 800,000 lbs (.037) = $29,600/day Generated
- 8,326/day Fixed Cost
- 616/day Variable Cost

$20,658/day Profit

Wood Shavings: 800,000 lbs (.038) = $30,400/day Generated
- 8,326/day Fixed Cost
- 560/day Variable Cost

$21,514/day Profit

9. This would generate on a yearly basis:

Rice Hulls: 24,082 (260) = $6,261,320

Peanut Shells: 20,658 (260) = $5,371,080

Wood Shavings: 21,514 (260) = $5,593,640

which would pay off the investment in two years.

10. Production required for a 5 year pay off.

$$\text{Cost per day} = \frac{9 \times 10^{6}}{5 \times 260} + 8{,}326 = \$15{,}249/\text{day}$$

$$\text{Rice Hulls: } \frac{15{,}249}{.041 - (.00049)} = 376{,}518 \text{ lbs/day}$$

= 188 tons/day

= 4,230 panels 1/2" x 4' x 8'/day

= 35 MM sq. ft of 1/2" board/year

$$\text{Peanut Shells: } \frac{15{,}249}{.037 - .00077} = 420{,}894 \text{ lbs/day}$$

= 210 tons/day

= 5,071 panels 1/2" x 4' x 8'/day

= 42 MM sq ft of 1/2" board/year

$$\text{Wood Shavings: } \frac{15{,}249}{.038 - .0007} = 408{,}820 \text{ lbs/day}$$

= 204 tons/day

= 4,867 panels 1/2" x 4' x 8'/day

= 40 MM sq ft of 1/2" board/year

The developed waste process is an economically viable venture. The breakeven rate is 110 tons per day or 21.5 million square feet of 1/2 inch board per year, or 671,875 panels 4' x 8' per year. On a full production of 400 tons per day the facility can be paid for in 2 years. On a 5 year pay off about 200 tons per day, or 37 million square feet of 1/2 inch board, or 1,227,893 panels 4' x 8' per year would be required.

Table 10

COMPARISON OF CONVENTIONAL WOOD SHAVING PLANT WITH A RICE HULLS OR PEANUT SHELL PLANT

Conventional Wood Shaving Plant *		Rice Hull or Peanut Shell Plant	
Unloading & Storage	120,000	Unloading & Storage	120,000
Milling & Drying	190,000	Acid Wash	100,000
Blending & Forming	490,000	Forming & Drying	150,000
Press Line	1,020,000	Press Line	1,020,000
Finishing Section	350,000	Finishing Section	350,000
Auxiliary Equipment	270,000	Auxiliary Equipment	175,000
Total Equip. Cost	2,440,000	Total Equipment Cost	1,915,000

* Reference (1) - 1967 Costs

TABLE 11

COST ANALYSIS OF ORGANIC PARTICLE BOARD

I. Standard 55 lb/ft^3 Commercial Particle Board

From Table 4: 30 lb/ft^3 Material Cost for 3/4" is .043/ft^2

55 lb/ft^3 Material Cost/ft^3 = \$1.261

II. Molded Rice Hulls Particle Board

1 cubic foot = 67 lbs.
Solution: 3% p-toluene sulfonic acid @ \$0.22/lb.
Amount Absorbed: 70 ml solution for every 100 g. rice hulls
Amount of Acid Used: $\frac{67 \times 454}{100} \times .07 = 21.29$ liters

$$\frac{21.29 \times 30}{454} = 1.41 \text{ lbs.}$$

Weight of Rice Hulls: 67-1.41 = 65.59 lbs.

Material Cost: Acid = 1.41 x .22 = .310
Rice Hulls = 65.59 x .0025 = .164

Material Cost/ft^3 = .474

III. Molded Wood Chips from this Process (Density as Tested)

1 cubic foot = 63 lbs.
Solution: 3% Phosphoric Acid @ \$0.12/lb.
Amount Absorbed: 200 ml solution for every 100 g. Wood Shavings.
Amount of Acid Used: $\frac{63 \times 454}{100} \times .2 = 57.2$ liters

$$\frac{57.2 \times 30}{454} = 3.78 \text{ lbs.}$$

Weight of Wood Chips: 63 - 3.78 = 59.22 lbs.

Material Cost: Acid = 3.78 x .12 = .454
Wood Chips = 59.22 x .0035 = .207

Material Cost/ft^3 = .661

IV. Molded Wood Chips with Equivalent Density to I.

1 cubic foot = 55 lbs.
Amount of Acid Used: $\frac{55 \times 454}{100} \times .2 = 49.94$

$$\frac{49.94 \times 30}{454} = 3.30 \text{ lbs.}$$

Weight of Wood Chips: 55 - 3.30 = 51.70 lbs.

Material Cost: Acid = 3.30 x .12 = .396
Wood Chips = 51.7 x .0035 = .181

Material Cost/ft^3 = .5770

V. Molded Corn Cobs Particle Board

1 cubic foot = 59 lbs.
Solution: 3% hydrochloric acid @ \$0.10/lb.
Amount Absorbed: 100 ml solution for every 100 g. of cob.
Amount of Acid Used: $\frac{59 \times 454}{100} \times .1 = 26.79$ liters

$$\frac{26.79 \times 30}{454} = 1.77 \text{ lbs.}$$

Weight of Corn Cobs: 59 - 1.77 = 57.2 lbs.

Material Cost:	Acid = 1.77 x .10	= .177
	Corn Cobs = 57.2 x .0075	= .429
	Material Cost/ft^3	= .606

VI. Molded Peanut Shells Particle Board

1 cubic foot = 62 lbs.
Solution: 3% Phosphoric Acid @ \$0.12/lb.
Amount Absorbed: 100 ml solution for every 100 g. of shells.
Amount of Acid Used: $\frac{62 \times 454}{100} \times .1 = 28.15$ liters

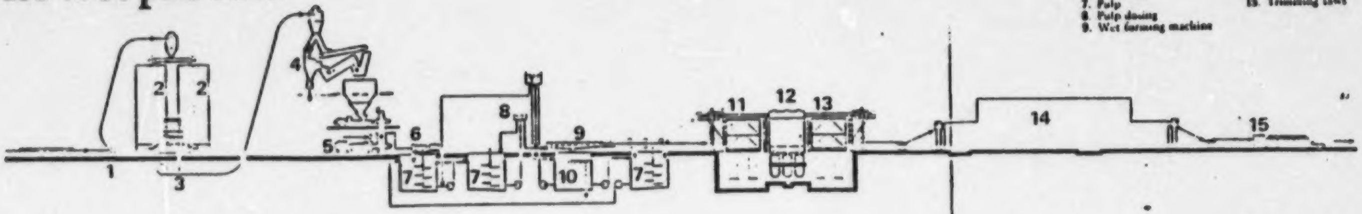
$$\frac{28.15 \times 30}{454} = 1.86 \text{ lbs.}$$

Weight of Peanut Shells: 62 - 1.86 = 60.14 lbs.

Material Cost:	Acid = 1.86 x .12	= .223
	Peanut Shells = 60.14 x .0075	= .451
	Material Cost/ft^3	= .674

Reproduced from best available copy.

The wet process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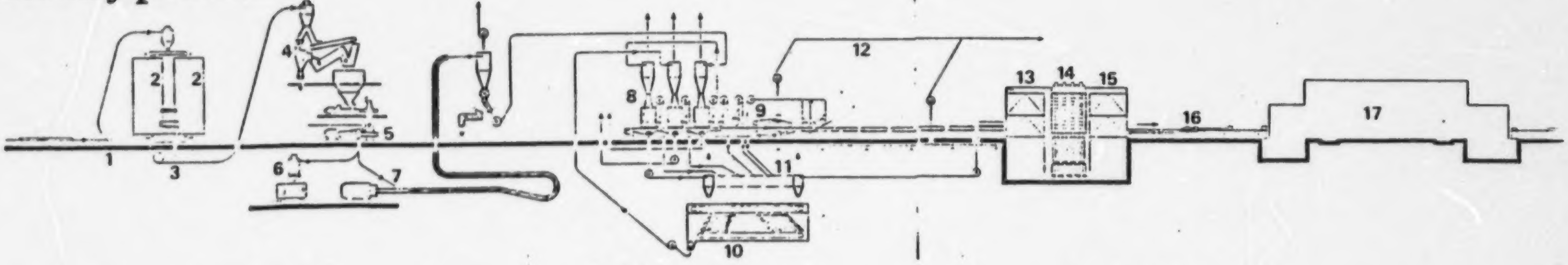
1. Chipper
2. Chip silos
3. Chip screen and rechipper
4. Chip washer
5. Defibrator
6. Raffinator
7. Pulp
8. Pulp dosing
9. Wet forming machine
10. White water bin
11. Loading hoist
12. Hot press
13. Unloading hoist
14. Heat treatment and humidification
15. Trimming saws

The wet process is the most firmly established method for the manufacture of hard, semi-hard and insulation board products.
It has been in use for more than 40 years, in the course of which considerable practical experience has been gained.

The experience, the simplicity of the method and the constant improvement of machinery, enables preset product capacity and quality to be reached easily and quickly.

The wet method is used for production lines with daily fiberboard outputs ranging from 20 to 250 tons, in thicknesses varying from 2 mm for hard and to 25 mm for insulation board.

The dry process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1. Chipper
2. Chip silos
3. Chip screen and rechipper
4. Chip washer
5. Defibrator
6. Start fiber cyclone
7. Dryer
8. Forming station
9. Precompressor
10. Fiber bin
11. Cyclones
12 Dust collector
13. Loading hoist
14 Hot press
15 Unloading hoist
16 Presaw
17. Conditioning
18. Trimming saws

The dry method is characterized by high production output, implying a lower production cost per ton of board.

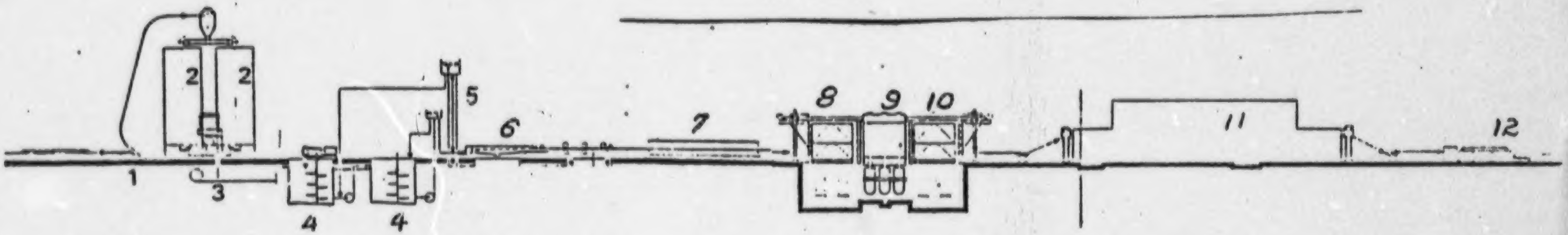
Board characteristics and thicknesses can be varied over a wide range and the production output is not appreciably affected when thicker board is produced.

FIGURE 4
COMMERCIAL PARTICLE BOARD PROCESS

FIGURE 5

WASTE PROCESS FOR PARTICLE BOARD

1. Material Feed
2. Material Storage
3. Feed to Treatment
4. Acid Wash
5. Acid-Water Mix
6. Wet Pre-Former
7. Drier
8. Loading Hoist
9. Hot Press
10. Unloading Hoist
11. Heat Treatment and Humidification
12. Trimming Saws



References:

1) Economics - Peter Vajda, First Washington State University Symposium on Particle Board, 1967.

2) The Economics of Particle Board Manufacture Revisited or an Assessment of the Industry in 1970 - Peter Vajda

APPENDIX C

M.S.C. TECHNICAL REPORT NO. 74-14

FACTORS TO BE APPLIED TO ESTIMATES OF DEVELOPMENT COSTS

2 AUGUST 1974

prepared for EPA Contract No: 68-03-2056

INTRODUCTION

The estimation of development costs for a product is a complex one and one that is prone to error. There are a multiplicity of steps involved in development. The best approach to establishing a cost would be as follows.

1. Estimate as accurately as possible the cost for for each step assuming 100% achievement of projected results.
2. Apply to the above estimate a factor of error. This factor where possible would be derived from similar type development.

The purpose of this study is to establish these factors.

This study will be based on the assumption that a laboratory scale process has been established to process the material. This process will have defined the parameter within which the manufacturing process and resulting product will be developed. The subsequent steps to product development and their associated factors for error in cost projection are discussed in the following text.

SELECT AND DEVELOP A MANUFACTURING PROCESS

Relationship of Time, Pressure and Heat - All composite material systems are processed by the manipulation of these parameters. Under special cases humidity and atmosphere could be involved to complicate matters. Most processes such as continuous lamination, molding, extrusion, and pultrusion are variable with time. Therefore, if a specific process was selected and the time relationship varied it would have minimal effect on the process. The resulting effect on cost would only be that necessary to establish the correct time relationship. A typical manufacturing process development program including machinery for a pilot plant could range between $300,000 and $500,000. A time study on a continuous processing line equivalent to that at MSC would require a maximum of four one half hour runs at about $500 per run for material, people and set up. This would have less than 1% effect on total cost.

Heat variable has little effect on the cost of the technique unless temperatures in excess of 400°F are involved. The materials processed in this study are under that. Therefore, any selected heat source would be capable of accepting a variable. The only cost involved would then be a study of temperature variables on the pilot plant. This would require longer duration runs and more of them. A temperature study could require eight one hour runs. This could have a possible 3% effect on the total cost.

Pressure has a much more serious effect on certain processes. In molding, extruding and pultruding it effects the capacity required. On a continuous lamination machine it effects the method of application. The products under evaluation here are of a large geometry. The increase in pressure then has an exponential effect. The equipment cost would conservatively be $5,000 per additional pound per square inch up to 5 psi. This cost would increase to $10,000 per additional pound per square inch up to 10 psi and $12,000 per additional pound per square inch up to 15 psi. Pressure above this would be limited to smaller specialty products. Modification to pilot plant design and installation would be in the $6000 to $7000 range. If the pilot plant is in the same price range as above, then the percent effect on cost can be estimated as shown in Table I. As the pressure increases so does the price of the pilot plant. Therefore, $300,000 would be used or a base estimate for 0-5 psi, $400,000 for 5-10 psi and $500,000 for 10-15 psi.

Humidity and atmosphere controls within the process effect cost dramatically. If such a control is required, it is recommended that a factor of at least 50% be utilized on the total cost.

Therefore, the factor (k) for time, pressure, heat, and atmosphere can be summarized as follows:

k_1= 100 (% effect on cost for the above variables)

.01 to .03 + C_o + .5 (Only if atmosphere is involved)

TABLE I

PRESSURE VARIABLE EFFECT ON COST

PRESSURE RANGE	% EFFECT	Co
0 - 5 psi	10%	.10
5 -10 psi	20%	.20
10 -15 psi	28%	.28

Then

$k_1 = 0.04 + C_o$ or $k_1 = 0.54 + C_o$ when atmosphere is involved.

General Design of Techniques - In order to estimate the development costs, the estimators have to have a general idea of the techniques that will be utilized. Therefore, variations in the techniques would have been accounted for in the original estimate and no additional factors would be required.

Range of Product Possibilities - The range of product possibilities would have to be understood to create the original estimates. The variations would primarily involve geometry. This in turn would effect shapes, forms, tools. In a typical wall panel, there could be at least three changes before development. The cost of typical in line process tools, and trimers plus set up charges are approximately $10,000 per change. However, at least 30% would be re-usable equipment. The effect then on total cost could be as much as 7%. The factor, k_2 would then be

$k_2 = 0.07$.

Select a Technique - The experimental set up for most techniques using a qualified facility would be an estimated $25,000. The worst condition possible would be that the technique would not work. Assuming at least 10% of the cost would be in equipment, such a failure would have an effect on the total cost of 8%. The factor, k_3, would then be

$k_3 = 0.08$.

Full Scale Experiments - Although a reasonable test program can be planned ahead of time, developed variables will create changes. Experience at MSC indicates that pre-planned experimental studies on machinery and process can vary as much as 23% on the average. Therefore, the factor, k_4, would then be

$$k_4 = .23.$$

Review the Results and Select a System - At this point there will be a considerable amount of data available. The selection will be based on achieving maximum reliability consistent with cost. This step will not create any variables that require consideration in the cost estimate.

Construct a Full Scale Pilot Plant - This will be an expansion of the experimental study. It will include automation, controls, and some scale up. In addition recent experience has shown that considerable inflation of outside purchased parts can be expected from the date of estimate to construction. Finally, there will be some parts that will not function as planned and will require modifications. MSC latest experience indicates in a complex pilot plant the above variances may increase the cost as much as 34%. Therefore the factor k_5 would then be

$$k_5 = .34.$$

Conduct Evaluation Runs and Modify - Once evaluation runs are conducted, certain design and process changes become apparent. This is particularly true of a complex system. The effect on cost from historical data at MSC can be as much as

5%. Therefore, the factor, k_6, would then be

$$k_6 = .05.$$

Develop Quality Control Procedures - These are known approaches that can be applied to any technique. There are no cost variance implications involved.

Summary - The total factor, K_I, that can be applied to an estimate for the selection and development of a manufacturing process can be developed as follows.

$$K_I = 1 + k_1 + k_2 + k_3 + k_4 + k_5 + k_6$$

Then for

Case I: No atmosphere control required

$$K_I = 1.81 + c_o$$

Case II: Atmosphere control required

$$K_I = 2.31\ c_o$$

DESIGN AND QUALIFY A PRODUCT

Select a Product - The product selection is based on marketing evaluation. If the selection is a poor one, then the entire development program is jeopardized. In that case the effect on cost variance would approach 100%. For the purpose of this study, it is assumed that the market selection is adequate to good. In this case their would be no effect on the development cost.

Design the Product - MSC experience in building product designs are quite extensive. However, in the design of a new product from new materials there are always surprises. Studies of case histories show both under variances and over variances resulting in an average of 5% increase in design cost. Therefore, the factor, k_7, would then be

$$K_7 = .05.$$

Construct Prototype Models - There are a considerable series of case histories to evaluate variances from at MSC on prototype construction. The variance results from misjudgement in fabrication time, designs that require modification, and miscalculation in material cost. The per cent of variance increase with the lower the projected prototype cost. To establish the variance factor here, the total of several project estimates were compared with the total of their actual cost. The study included three prototype houses and one set of prototype panels. The total estimated budget for these four was $56,690 and the actual total direct cost was $67,113. This results in an 18% increase over the budget. Therefore, the factor, k_8, can be established as

$$k_8 = 0.18.$$

Evaluate Modify and Re-evaluate the Prototypes - This evaluation would be analytical for cost and aesthetic characteristics and experimental for mechanical and physical properties. The major variances occur where there is a system failure and modifications and subsequent re-evaluation must be done. Case histories at MSC would indicate a potential variance of 19%. Therefore, the factor k_9, would then be

$$k_9 = 0.19.$$

Construct Specimens, Conduct Qualification Tests, Analyze, Modify and Retest - This is an outside evaluation of the product usually on a larger scale than the previous tests. Since the evaluation is different, experience would indicate this factor would be a duplicate of the one above. Therefore,

$$K_{10} = 0.19.$$

Submit the Results to Specific Agencies - The above data has to be placed into report form and submitted in a prescribed manner to a particular qualifying agency. The cost for this can be closely projected. There would not be a variance of any consequence.

Coordination with the Agency - The coordination until receipt of approval involves personalities and the particular characteristics of the agency. Experience would indicate that a 15% cost variance on the estimate should be included. Therefore,

$$k_{11} = 0.15.$$

Summary - The total factor, K_{II}, that can be applied to the design and qualification of a product can be developed as follows.

$$K_{III} = 1 + k_7 + k_8 + k_9 + k_{10} + k_{11}$$

Then,

$$K_{II} = 1.76$$

APPLY PRODUCT TO THE MARKET

Review and Select a Market - The various markets for the product or products are reviewed. A selection is then made of the ones that offer the most potential. The cost of such a market survey is a controlled one. That is a given number of manhours are expended to collect data and at the completion of the manhours the data is reviewed and a selection made. No over run factor need be considered.

Evaluate Methods of Market Penetration - This is a controlled study also. An established amount of manhours is expended to collect data on various marketing methods. At the end of this expenditure, the data is reviewed and summarized for a selection. No overrun factor need be considered here also.

Select a Method - The above information is used to select a method that offers the greatest return on development investment plus market investment. This is accomplished within the framework of a controlled program so an overrun is not probable.

Proceed to Market - In most cases this will involve prototypes and models. K_{II} should be applied to these specific investments. This marketing effort is to some degree controlled. Periodic evaluation of results permits corrections and re-directions and thus reduces potential overruns. Without such periodic checks, a variance of 100% could easily be achieved. By carefully controlling the program it may be possible to restrict potential variances to 20%. Therefore,

$$K_{III} = 1.20.$$

PRODUCT ACCEPTANCE

First Level Acceptance - This is the reaction of the distributor, builder or user. These individuals generally will not use the product as is unless it has an acceptance record. Therefore, it will always be necessary to collect their comments for action if sales are to be made. This is again a controlled program with limited probability of variance.

Reaction to the Above - A review of the above comments will be made and reactions will be initiated under marketing, engineering, and production guidance. An estimate can be made for this cost. However, the variance can be extreme. It is recommended that a factor of

$$k_{12} = 0.30$$

be used.

Second Level Acceptance - This is the reaction of the consumer. Again this will be a controlled program of a survey type. The results will in most cases be less dramatic than the first level survey which has already provided a high degree of consumer acceptance. No variation factor need be considered.

Reaction to the Above - Since the major corrections have already been made, the actions required will be minimal in nature. However, it will be very difficult to estimate these costs. A variance factor of

$$k_{13} = 0.10$$

should be used.

Summary - The estimate for product acceptance can be controlled with the exception of corrective actions required. Therefore,

$$K_{IV} = 1 + k_{12} + k_{13}$$

then

$$K_{IV} = 1.40.$$

APPLICATION OF FACTORS OF COST

A. Select and Develop a Manufacturing Process

1. Estimate cost - A
2. Compute Probable Cost - C_A

$$C_A = AK_I$$

where $K_I = 1.81 + Co$ - No atmosphere control required

$K_I = 2.31 + Co$ - Atmosphere Control required

B. Design and Qualify a Product

1. Estimate a cost - B
2. Compute Probable Cost - C_B

$$C_B = BK_{II}$$

where $K_{II} = 1.76$

C. Apply Product to the Market

1. Estimate a cost - C
2. Compute Probable cost - C_C

$$C_C = CK_{III}$$

where $K_{III} = 1.20$

D. Product Acceptance

1. Estimate a cost - D
2. Compute Probable cost - C_D

$$C_D = DK_{IV}$$

where $K_{IV} = 1.40$

APPENDIX D

MSC TECHNICAL REPORT NO. 74-15

CODE QUALIFICATIONS FOR BUILDING PRODUCTS

By S. Feher

5 August 1974

Prepared for EPA Contract No. 68-03-2056

Definitions

ICBO	International Council of Building Officials
UBC	Uniform Building Code
BOCA	Building Officials Conference of America Inc.
SBC	Southern Building Code
FHA	Federal Housing Administration
VA	Veterans Administration

CODE QUALIFICATION

All new materials and structural components intended for use in residential construction in the United States must be approved under one of the three major model codes, UBC, BOCA, or the SBC. In addition FHA and VA approval may also be required if the product is involved in construction projects financed by these agencies.

During the last few years several states have passed so called "Factory Built Housing Laws". Under the provisions of these laws the state can approve new industrialized building systems and components. This approval must be honored by local building officials without enforcement of local regulations on those aspects of the construction specifically approved by the state. All other aspects must meet local code requirements. Since most Factory Built Housing Laws specify that use of one of the three, model codes as the basis of performance criteria the requirements for qualification of new materials and building components under the state approval is practically the same as those under the model codes. The state approvals do not supersede FHA or VA approvals.

In the following discussion typical requirements for qualification under UBC and FHA regulations will be outlined for various building components utilizing new materials and/or new methods of construction.

UBC AND FHA REQUIREMENTS

The UBC is the most widely used model code in the country and it has the most stringent design criteria among the model codes in such critical areas as earthquake and fire safety. The UBC is controlled and published by the International Conference of Building Officials (ICBO), which maintain a permanent Research Committee for the purpose of evaluating applications for UBC acceptance of new materials and construction methods. The ICBO Research Committee has certain standard requirements for new materials for specific applications; however, in most cases when new construction methods are proposed in combination with new materials the Research Committee staff will specify the supporting technical data required for approval. The sponsor of the proposed product is required to generate the specified data being actual test data or engineering calculation. This data must be certified by an independent test laboratory or qualified independent engineer or architect.

Upon review and acceptance of the supporting data the Research Committee staff prepares its recommendations for approval which the full community acts on in their regular monthly meetings. If approval is granted an ICBO Research Committee Recommendation Bulletin is issued and is distributed to all members of ICBO which includes most local building departments. Although the local building officials is not obligated to approve the use of a new material or construction method covered by an ICBO Bulletin in most cases the ICBO Bulletin assures local acceptance of the product or method of construction.

FHA acceptance of new materials and construction methods is granted through the issuance of Structural Engineering Bulletins. The supporting technical data required for FHA approval is much the same as that required by ICBO. In case of FHA the data submitted by the sponsor is evaluated by the HUD/FHA Central Offices, Architectural and Engineering Standards staff in Washington D.C. The SEB when issued is distributed to all FHA field offices nation wide and assures local acceptance of the new product in FHA insured construction projects.

The supporting data required by ICBO and FHA for qualification of new materials and/or construction methods varies widely depending on the nature of the product being considered. For the purpose of the following discussion it will be assured that the materials being developed will be used in prefabricated, sandwich panel structural building components.

MATERIAL QUALIFICATION

If new materials are considered for use as stressed skins or loadbearing core of sanwich panels the first step in their qualification is to conduct sufficient testing to establish a reliable level of minimum mechanical properties to be used in engineering design calculation and to serve as the criteria for material acceptance in production quality control. The most important mechanical properties are the following.

Tensile Strength
Modulus of Elasticity
Compressive Strength
Shear Strength

In addition to the requirement to establish the mechanical properties listed above the material must meet fire safety and durability requirements depending on its intended use and exposure.

Exterior wall facing materials must be tested for:

Flame Spread
Smoke Generation
Water Permeability
Weatherability

Interior wall facing and core materials must be tested for:

Flame Spread
Smoke Generation

In addition to the above test requirements the use of new facing and core materials will necessitate in most cases to requalify the adhesives used in factory and field assembly of the panel components. Adhesive qualification required the following tests:

-- Block shear test after accelerated aging
-- Lap shear test after accelerated aging
-- Flatwise tensile test after accelerated aging
-- Creep test before and after accelerated aging at room temperature and at elevated temperature
-- Block shear test after high humidity mold environment aging

STRUCTURAL COMPONENT QUALIFICATION

Exterior Loadbearing Wall Panels

The ability of a proposed wall design to withstand the various loads due to wind, earthquakes, snow etc. can be shown analytically by use of well known engineering principles in case of simple, conventional designs utilizing standard building materials with well established mechanical and physical properties. However, in case of complex sandwich panel construction, utilizing new materials, actual full scale physical testing is the only reliable way of establishing design load capacity.

The tests required are the following:

- Axial compression test
- Transverse load test
- Racking shear test
- Impact test

Each test must be conducted on a minimum of three specimens and if the test results have more than 15% variation a total of five specimens must be tested.

In addition to the structural tests exterior walls must also pass a minimum 20 minute loadbearing fire endurance test. (This is an FHA requirement only.)

Interior Loadbearing Wall Panels

The tests required of interior load bearing walls are the same as those for exterior walls with the exception of lower load requirements in case of transverse loading since the interior walls are not exposed to direct wind loading.

A special core interior wall is a party wall separating two dwelling units. Party walls usually require a minimum of 1 hour fire rating and accoustical performance of STC 50 or better. The fire rating can only be verified by actual fire test. Accoustical performance, however, can be derived by comparison of the proposed wall design with similar construction previously tested.

Interior Non-Loadbearing Wall Panels

The only requirement is to demonstrate 5 psf transverse load capacity.

Roof Panels

Roof panels are generally designed for a specific span to withstand various magnitude live loads in addition to their own weight (dead load) within the allowable deflection limits.

Transverse loading tests under short term and long term (creep) loading conditions must be performed for each combination of span and design live loads.

In addition to the structural tests roof panels must be tested for roof fire classification A, B, or C unless the roofing material and sheeting has previously been classified.

If the under side of the roof panel is used as the finished ceiling it also must be able to pass a 15 minutes roof/ceiling fire endurance test (FHA requirements only).

Of course any roof panel system must be impervious to water. There is no specific test requirement for water penetration but general industry standard is 20 years service life without re-roofing.

Floor Panels

As is the case of roof panels, floor panels are designed for specific spans and live loads. Therefore, transverse loading tests under short and long duration loading conditions must be conducted for each specific continuation of span and design loads the panels are intended to be used for.

Floor panels must also be tested for concentrated load bearing capacity.

Fire endurance test requirements depend on the type of dwelling the floor panels will be used in. Single family homes must have 15 minutes rated ground floor and 20 minutes rated floor/ceiling assemblies. (FHA requirement only.) Apartment houses with separate occupancy of upper and lower units must have minimum 1 hr rated floor/ceiling assemblies.

TABLE I

SUMMARY OF CODE QUALIFICATION TESTS OF A NEW BUILDING SYSTEM UNDER ICBO & FHA REQUIREMENTS

COMPONENT	TESTS REQUIRED	APPROX COST
1. Exterior Wall & Roof Facing Sheet:	Mechanical Properties	$1,000
	Flame Spread	500
	Smoke Generation	300
	Water Permeability	300
	Weather-ometer	2,000
2. Interior Wall & Ceiling Facing Sheet:	Mechanical Properties	$1,000
	Flame Spread	500
	Smoke Generation	300
3. Exterior Load-bearing Wall:	Axial Compression	$5,000*
	Transverse Loading	
	Racking Shear	
	Impact	
	20 min fire test (FHA)	2,500
4. Interior Load-Bearing Wall:	Axial Compression	$5,000*
	Transverse Loading	
	Racking Shear	
	Impact	
	20 Min Fire Test (FHA)	2,500
	Party Wall 1 hr Fire Test	4,000

TABLE I CON'D

COMPONENT	TESTS REQUIRED	APPROX COST
5. Internal Non-Load-bearing Wall:	Transverse Loading	$1,000*
6. Roof Panels:	Transverse Loading	
	Short Duration	$1,000*
	Long Duration	2,000*
	Fire Classification	2,500
	15 min Fire Test (FHA)	2,500
7. Floor Panels:	Transverse Loading	
	Short Duration	$1,000*
	Long Duration	2,000*
	Fire Tests	
	15 min. Ground Floor	$5,000
	20 min. Floor/Ceiling	5,000
	1 hr Floor/Ceiling	5,000

*Testing performed in Company's own facilities under independent testing agency supervision.

Appendix E

MSC TECHNICAL REPORT 75-001

DESIGN AND TEST CRITERIA
FOR DWELLING SEPARATION WALL ASSEMBLIES
(PARTY WALL)

PREPARED FOR:
ENVIRONMENTAL PROTECTION AGENCY CONTRACT
No. 68-03-2056

Prepared By:
Jere Robinson
Stephen I. Feher

INTRODUCTION

This report has been prepared to outline criteria for the design and test for dwelling separation walls (party wall) utilizing new materials in sandwich panel type construction.

The requirements are limited to defining the performance criteria of a specific structural element and not the entire building. Because physical and mechanical characteristics of the new materials that may be developed for this application are unkown at this time, the design requirements and test methods specified in this report are of a general nature and they will have to be modified and expanded to accommodate the specific materials. The general design and test criteria in this report are based on the HUD guide criteria developed by the National Bureau of Standard for Operation Breakthrough with modifications reflecting more stringent requirements where applicable specified by the 1973 edition of the FHA minimum property standards or the 1973 edition of the Uniform Building Code and the requirements of the International Conference of Building Officials (ICBO) for qualification of new construction materials and methods.

SUMMARY OF REQUIREMENTS

1. STRUCTURAL SERVICEABILITY
   - 1.1 Horizontal deflection
   - 1.2 Occupancy loads
2. STRUCTURAL SAFETY
   - 2.1 Axial load
   - 2.2 Racking shear load
3. FIRE SAFETY
   - 3.1 Fire endurance
   - 3.2 Flame spread
   - 3.3 Smoke generation
   - 3.4 Potential heat (combustibility)
4. ACOUSTIC SEPARATION
   - 4.1 STC rating

1. STRUCTURAL SERVICEABILITY

1.1 HORIZONTAL DEFLECTION

Requirement

Horizontal deflections of vertical structural elements between two successive levels of horizontal support should not impair the serviceability of the structure.

Criterion

Horizontal deflections of vertical structural elements, including interior space dividers under service loads as defined hereafter, are to be sustained without:

1.1.1 delamination, spalling, or other local damage to any element,

1.1.2 damage to windows and paneling and malfunctioning of windows and doors,

1.1.3 damage to the built element itself and to other interfacing built elements,

1.1.4 damage to mechanical and service systems,

1.1.5 loss of weather tightness by separation of windows from outside paneling, separation of wall panels from floor or ceiling and/or separation between panels,

1.1.6 undesirable esthetic effects of discomfort caused to occupants by apparent lack of stiffness.

In addition, the following deflection limitations should be met:

1.1.7 horizontal deflections due to a uniformly distributed transverse load of 5#/ft^2 should not exceed "l"/240. Where "l" is the height of the wall between horizontal structural elements which are capable of reacting the transverse load acting on the wall.

Test

Transverse load bending test per ASTM-E-72 and ICBO Research Committee Acceptance Criteria for Sandwich Panels (tentative draft, July 1974) Appendix A.

1.2 OCCUPANCY LOADS

Requirement

Inter-dwelling walls should not be damaged by occupancy loads.

Criterion

Walls should resist the following loads with a maximum residual deflection not exceeding 10 per cent of total maximum net deflection of "l"/4000, whichever is greater, measured 24 hours after removal of the superimposed load, and with no damage to surfaces, finishes, supports or subsystems:

1.2.1 A concentrated horizontal load of 150 lb, applied at any location to a bearing area not to exceed 5 in^2, and centered 3 in above finished floor level,

1.2.3 a load of 10 lb/ft^2 applied horizontally over the entire vertical surface of one side of the wall.

1.2.4 a load, equal, to 40 lb per linear foot or 1.5 times the maximum load likely to be exerted by attached shelves and modular furniture, whichever is greater, applied at an eccentricity with respect to the geometric centerline of the space divider of 1/2 the space divider thickness + 6 in. Space dividers to which shelves or furniture cannot be attached are exempt from this requirement.

1.2.5 an impact energy of 60 ft-lb, applied horizontally at any location five consecutive times, except in the case where the wall consists of stiffening elements supporting a surface cover. In the latter case, the wall should resist the 60 ft-lb impact energy delivered five consecutive times to the surface cover coincident with the axis of the stiffening element and a 30 ft-lb impact energy delivered five consecutive times to the surface cover at any other location.

In specific cases, where local repairs of surface covers may be readily accomplished without leaving objectionable traces, using available materials and methods that do not require specialized skills, the concentrated load in 1.2.1 and 1.2.2 may be reduced to 100 lb, and the 30 ft-lb impact energy in 1.2.5 may be reduced to 7.5 ft-lb.

Test

Analysis and/or full-scale testing of structural subassemblies. For Criterion 1.2.5, testing apparatus as described in ASTM E 72.

Commentary

This is a serviceability Criterion for walls under occupancy load, relating primarily to local failure:

1.2.1 is related to human activity (bearing, butting, etc.),

1.2.2 is related to impact by furniture, kicking, etc., at a low elevation,

1.2.3 relates to the overall minimum strength desirable for walls,

1.2.4 guards against failure caused by attached shelves and modular furniture, and

1.2.5 differentiates between the stiffening elements and the surface cover, since stiffening elements are more difficult to replace.

2. STRUCTURAL SAFETY

2.1 AXIAL LOAD

Requirement

The wall panel assembly should have sufficient strength to support all live and dead loads acting on it in a given building.

Criterion

The allowable axial load is established as 1/3 of the average failure load of the panels determined in full scale test.

Test

Axial compression load test per ASTM E 72 and ICBO Research Committee Acceptance Criteria for Sandwich Panels (Tenative Draft, July 1974) Appendix A.

2.2 RACKING SHEAR LOAD

Requirement

The wall panel assembly shall have sufficient racking shear resistance to facilitate efficient design of shear walls to withstand lateral wind and earthquake loads acting on the building.

Criterion

The allowable racking shear load is established as the shear load at which a net horizontal deflection of ½-inch occurs, the ultimate load decided by a factor of safety of 3 or the allowable fastener loads whichever is the lowest.

Test

Racking shear test in accordance with ASTM E 72 and ICBO Research Committee Acceptance Criteria for Sandwich Panels (Tentative Draft, July 1974) Appendix A.

3. FIRE SAFETY

3.1 FIRE ENDURANCE

Requirement

The walls should be able to contain the fire for a period sufficient to permit evacuation of occupants and for fire fighters to bring the fire under control.

Criterion

The dwelling separation walls should have fire endurance based on the type of building in which they are used as given in Table 3.1.

TABLE 3.1 FIRE ENDURANCE CRITERIA FOR DWELLING SEPARATION WALLS

BUILDING TYPE	FIRE ENDURANCE
Single Family Detached Between Dwelling & Garage	1 hr
Single Family Attached Between Dwelling Units	1½ hrs
Multi-Family Lowrise all Load Bearing Walls Supporting An Upstairs Floor of Another Dwelling and all Walls Between Dwelling	1 hr
Special Fire Walls Large Building Area Separation	2 hrs

Test

Fire endurance rating of a wall assembly should be determined by full scale fire test per ASTM E 119.

3.2 FLAME SPREAD

Requirement

Flame spread characteristics of wall surfaces should minimize the hazard of spreading the fire inside the dwelling.

Criterion

The flame spread characteristics of the wall surfaces should relate to the use of the enclosed space as specified in Table 3.2.

TABLE 3.2 FLAME SPREAD RATING REQUIREMENT FOR FOR INTERIOR WALL SURFACES

LOCATION WITHIN BUILDING	FLAME SPREAD RATING (Maximum Allowable)
Enclosed Stairways & Other Vertical Openings	25
Corridors or Hallways & Other Exits	75
Within Living Unit except for Kitchen	200
Kitchen Space within Living Unit	75
Public Rooms & Entrance Spaces	75
Lobbies & Corridors between Exit Stairway & Exterior	25
Service Rooms, enclosing Heat Producing or other Mechanical Equipment, & all other Fire Hazardous Areas	25

Test

Flame spread rating for wall surface materials shall be determined in accordance with ASTM E 84 "Tunnel Test".

3.3 SMOKE GENERATION

Requirement

Smoke generated by the burning of the wall surface should not endanger the life of the occupant and allow for safe evacuation of the building.

Criterion

The only existing firm criterion for maximum allowable smoke generation is the 450 limit specified by the Uniform Building Code and as determined by the ASTM E-84 "Tunnel Test". The FHA Minimum Property Standards (MPS) has no firm requirement at present "reserved-pending evaluation of test procedures".

The Operation Breakthrough requirements are the most stringent and specific as listed in Table 3.3. These requirements have not been adopted yet by FHA or ICBO but they are under serious consideration by both agencies. Therefore, any new material developed should meet these requirements.

TABLE 3.3 SMOKE GENERATION RATING REQUIREMENT FOR INTERIOR WALL SURFACES

LOCATION WITHIN BUILDING	SMOKE GENERATION RATING
All Interior Living Space	300
Service Rooms, Enclosing H Producing or other Mechanical Equipment and all other Fire Hazardous Areas	150

Test

The smoke generation ratings listed in Table 3.3 are based on measurements made by the "NBS Chamber Method" (ASTM STP 422)

Commentary

Limiting smoke generation is a new fire safety requirement, the introduction of which is based on demonstrated need in this area. The smoke levels represent our best judgment and yet permit the use of most materials commonly considered safe. Though the problem of toxic gases is recognized, at this time there are insufficient data to specify limits. However, the toxic levels may be evaluated in comparison with those produced by cellulosic materials. As a general guideline; combustion products should be no more toxic than those generated by burning of untreated wood.

3.4 POTENTIAL HEAT (Combustibility)

Requirement

The amount of heat contributed to the fire by the materials used in the walls should be limited.

Criterion

The allowable potential heat (combustibility) of the wall assembly is limited based on the type of building in which the wall is used. In general wall assemblies are classified as combustible or non-combustible as follows:

CRITERIA FOR NON COMBUSTIBLE CLASSIFICATION

HUD/NBS CRITERIA:

3.4.1 Potential heat 8000 BTU MAX. for 1 Ft^2 section cut through the wall, excluding surface finish.

UBC CRITERIA;

3.4.2 Material of which no part will ignite and burn when subjected to fire. Any material conforming to U.B.C. Standard No. 4-1 shall be considered noncombustible within the meaning of this Section.

3.4.3 Material having a structural base of noncombustible materials as defined in 3.4.2 above, with a surfacing material not over 1/8 inch thick which has a flame-spread rating of 50 or less. "Noncombustible" does not apply to surface finish materials. Material required to be noncombustible for reduced clearances to flues, heating appliances, or other sources of high temperature shall refer to material conforming to 3.4.2. No material shall be classed as noncombustible which is subject to increase in combustibility or flame-spread rating beyond the limits herein established, through the effects of age, moisture or other atmospheric condition.

Flame-spread rating as used herein refers to rating obtained according to tests conducted as specified in U.B.C. Standard No. 42-1. (Same as ASTM E 84 "Tunnel Test").

Test

Potential heat of a wall assembly may be calculated if the properties and quantities of the component materials making up the wall assembly are known. Otherwise it should be determined by experimental measurements in accordance with ASTM Proceedings 61 (1961), "Potential Heat - A Method for Measuring the Heat Release of Materials in Building Fires," by J.J. Loftus et al.

For UBC criteria see test specified in 3.4.2 and 3.4.3.

4. ACOUSTIC SEPARATION

4.1 STC RATING

Requirement

The dwelling separation wall should provide sufficient accoustical isolation to insure privacy of the individual dwellings.

Criteria

The dwelling separation wall should have o-minimum Sound Transmission Class rating of 50.

Test

Sound Transmission Class shall be determined in accordance with ASTM E 90.

Commentary

An STC rating of 50 is the minimum requirement by FHA and UBC. However considerably higher ratings may be desired by architects and builders for marketing reasons.

Appendix F
MATERIAL SYSTEMS
ETR NO. 71

ON

THE CONSTRUCTION AND TESTING OF AN INORGANIC PANEL

June 16, 1975

Prepared By J Robinson
J. Robinson

Approved By S. Feher
S. Feher

MSC PROPRIETARY DATA
FOR INTERNAL COMPANY USE ONLY

1. Summary and Conclusions

A panel was fabricated, at the Material Systems chemistry laboratory during the month of May 1975, of inorganic materials. It was subsequently tested in both flexure and axial compression. It was found to have greater than twice the flexural rigidity and almost twice the ultimate axial compression capability of a standard gypboard/gypboard interior type panel.

2. Test Specimen

The single specimen was fabricated in the configuration of Fig 1. It was made in two halves and subsequently bonded together using inorganic adhesive*. The panel halves were first formed in a mold utilizing a rice hull/plaster mix as follows:

-Rice Hulls	100 gms
-90-Minute Casting Plaster	300 gms
-3/4" Long Glass Fibers	5 gms
-761 PVAC (Polyvinyl Acetate Adhesive)	40 gms
-Fungicide (BUSAN 30)	.5 gms
-Water	220 gms

An .060 thick inorganic laminate consisting of 1½ oz. glass mat impregnated with inorganic compound** was then applied to each half as shown. The exterior surfaces received a trowelled on layer of plaster approximately .060 thick.

3. Test Equipment

The flexure test was performed by adding dead weights to the panel as shown in Fig 2A. Concrete blocks weighing 40 lbs each were used for incremental loading. Deflections were measured as shown with three (3) deflection gauges.

The axial compression test was performed in the panel axial compression test set-up shown in Figs 3 and 6. All instrumentation details were as shown with four (4) deflection gauges with rods, deflecto meter mirror, scale and wire. Only 2 lateral guides were used.

---

* Adhesive 63-97

$MgCl_2$-$6H_2O$, 32° BE	109 gms
MgO (Fast Thompson)	100 gms
CAB-O-SIL (M-5)	1 gm
1/8" Glass Fibers (K832)	6 gms

**$MgCl_2$-$6H_2O$, 22° BE	104 gms
MgO (Fast Thompson)	100 gms

4. Test Procedures

A. Flexure Test

The flexure test (a non-destructive test) was administered first by adding one (1) 40 lb concrete block to each load point at a time and observing deflections. A total of 10 blocks or 400 lbs (equivalent of 25 lbs/ft^2) was applied with uniform recorded deflections.

The blocks were removed two at a time at 5-minute intervals (to allow for any creep) and the resulting set measurements noted.

B. Axial Compression Test

The panel was taken to failure in the axial compression test which was conducted per the ASTM E 72 criteria. Loading was applied at 1000 pounds or 500#/ft intervals following a 400#/ft preload after which all gauges were zeroed. Following each load application, the load was relaxed and the set readings were noted.

5. Test Observations and Results

A. Flexure Test

The results of this test are shown in Fig 2A and Fig 4 along with curves from similar previous test conducted on MSC Duftec panels. Since the panel was not tested to failure, comparison of ultimate flexural strength with Duftec panels is not possible. It is obvious from the load vs deflection curves that the stiffness of the inorganic panel is much higher than that of similar thickness Duftec panels.

B. Axial Compression Test

The test results are shown below:

Load	Deflection									
	Mirror	#1	Set	#2	Set	#3	Set	#4	Set	Avg
500#/ft	0	.003	0	.003	0	.003	0	.006	0	.0040
1000	0	.005	0	.005	0	.007	0	.010	0	.0067
1500	0	.008	0	.008	0	.011	0	.013	0	.0100
000	.020	.009	0	.011	0	.016	.001	.016	.001	.0120
2500	.030	.013	0	.013	0	.020	.001	.022	.002	.0170
3000	.040	.014	0	.017	0	.026	.002	.026	.002	.0206
3500	.050	.019	0	.018	0	.029	.002	.032	.002	.0244
00	.060	.024	0	.018	0	.032	.003	.040	.003	.0285
0	.070	.030	0	.029	0	.048	.007	.052	.008	.0397
	.080	.034		.032		.062	.009	.065	.010	.0482

FAILURE

These results are plotted in Fig 5 and are compared to others previously tested.

The specimen failed at an ultimate load of 7000 pounds per foot by a general splitting of the inorganic adhesive bondline at the nodes of the two panels and some fracturing of the facing at the upper plate line as shown in Figs 7 and 8.

Due to the 3/4" eccentricity of the applied load, a certain amount of lateral panel deflection was detected and it was, probably this differential bending, which ultimately forced the bondline failure.

6. CONCLUSIONS AND RECOMMENDATIONS

Figures 4 and 5 shows the inorganic panel to be dramatically stiffer and stronger than the standard MSC Duftec panels. This is hardly surprising, however, since it has a crossection of approximately 35 in^2/ft compared to the 10 in^2/ft and 15 in^2/ft of the ICBO exterior and interior specimens respectively.

In addition, it has a moment of inertia of approximately 134 in^4/ft (see calculations) as compared to the approximate 14 in^4/ft amd 43 in^4/ft of the other panels respectively.

These results show that the new wall concept has more than sufficient strength and stiffness for performing the same functions as the existing Duftec wall designs. The new wall concept could be further refined by reducing its weight with minimum loss of strength and stiffness.

Comments: Panel was obviously over-designed. Therefore the comparison is not fair. A maximum acceptable panel weight shall be determined for handling on site. Fire tests and structure tests of a wet panel should be conducted. B. Lesaf

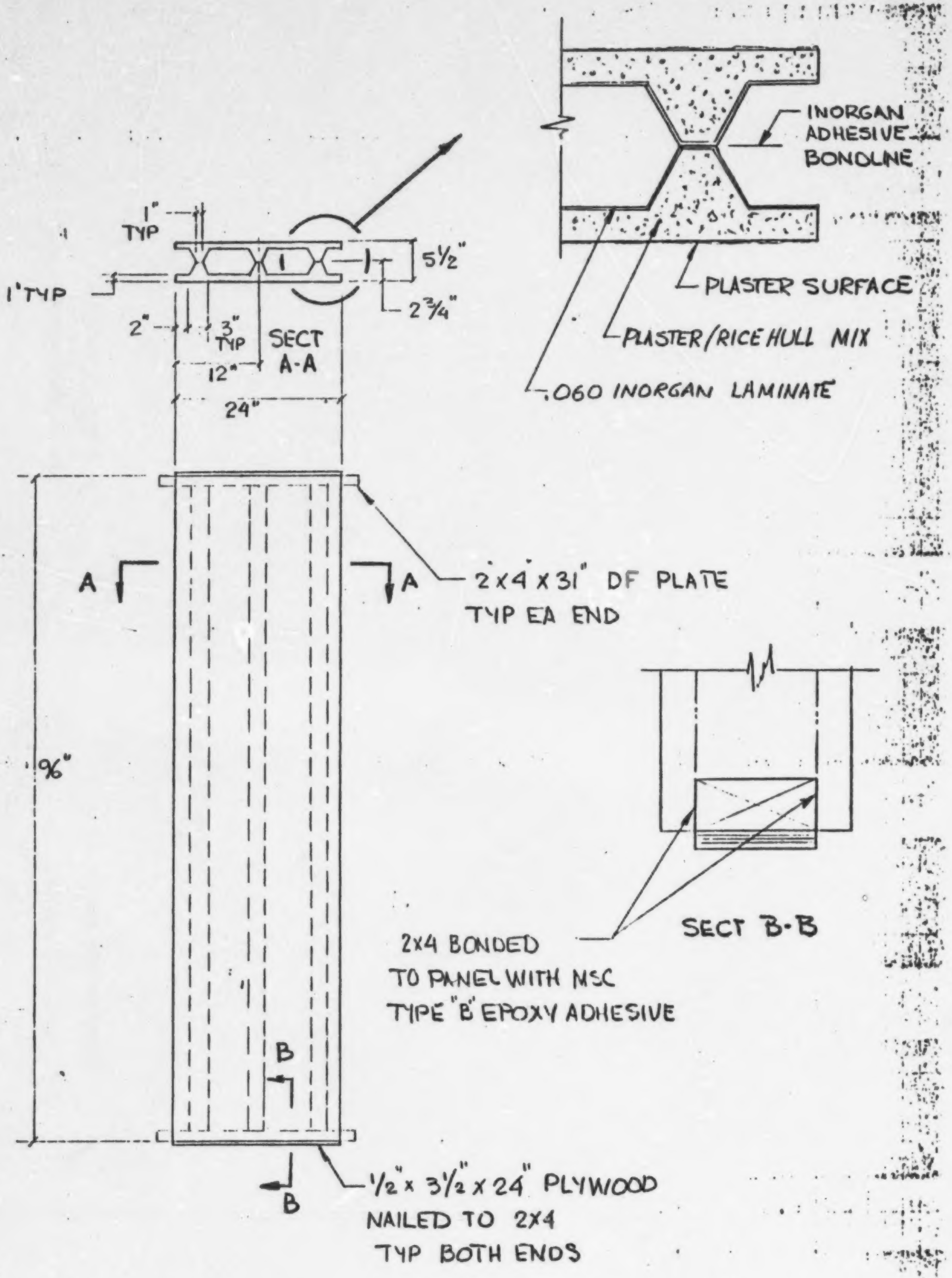

1" TYP
1"TYP
5½"
2¾"
2"
3" TYP
12"
24"
SECT A-A
INORGAN ADHESIVE BONDLINE
PLASTER SURFACE
PLASTER/RICE HULL MIX
.060 INORGAN LAMINATE
A
A
2x4x31" DF PLATE TYP EA END
96"
SECT B-B
2x4 BONDED TO PANEL WITH NSC TYPE "B" EPOXY ADHESIVE
B
B
½"x 3½"x 24" PLYWOOD NAILED TO 2x4 TYP BOTH ENDS

FIG I
INORGAN SPECIMEN

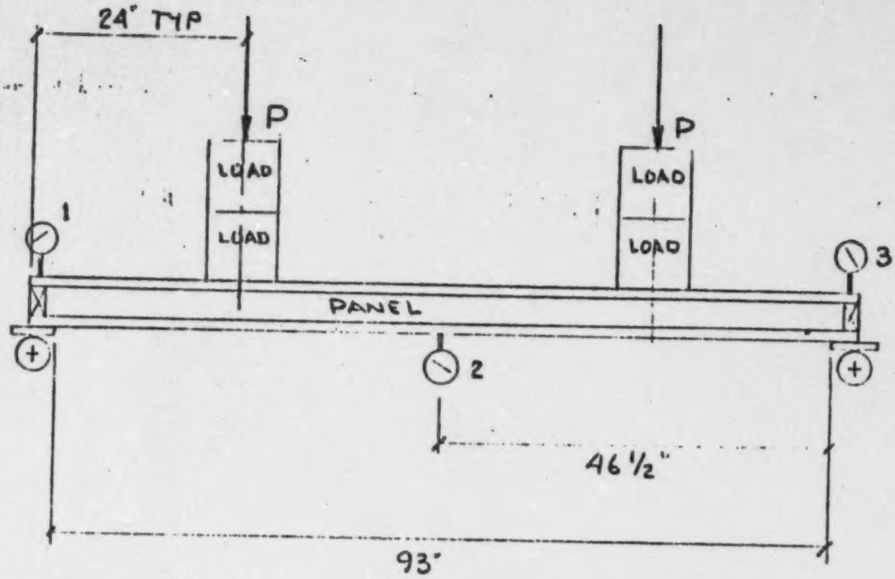
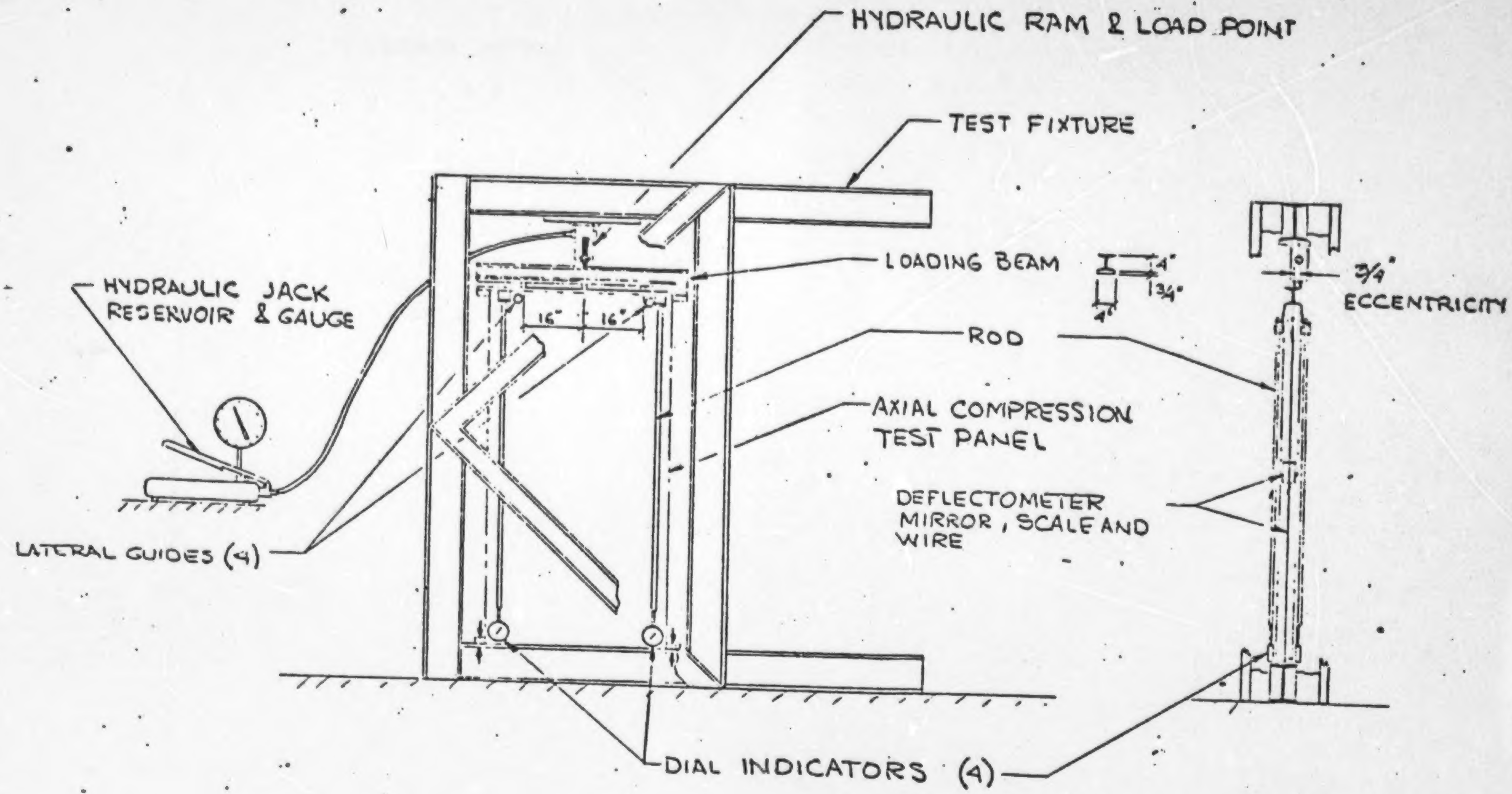

24" TYP
P
LOAD
LOAD
P
LOAD
LOAD
1
3
PANEL
2
46 1/2"
93"

FIG 2 A
FLEXURE TEST ARRANGEMENT

FIG 2 B
DEFLECTION DATA

LOAD		GAUGES					
#/FT^2	P	1	SET	2	SET	3	SET
0	0	.100	.093	.200	.202	1.100	1.000
5	40#	.095	.087	.209	.215	1.099	1.098
10	80#	.090	.081	.218	.224	1.097	1.096
15	120#	.084	.087	.228	.234	1.096	1.095
20	160#	.078	.077	.239	.242	1.094	1.094
25	200#	.071		.249		1.093	


HYDRAULIC RAM & LOAD POINT
TEST FIXTURE
LOADING BEAM
4"
1 3/4"
4"
3/4"
ECCENTRICITY
HYDRAULIC JACK
RESERVOIR & GAUGE
16"
16"
ROD
AXIAL COMPRESSION
TEST PANEL
DEFLECTOMETER
MIRROR, SCALE AND
WIRE
LATERAL GUIDES (4)
DIAL INDICATORS (4)

MATERIAL SYSTEMS CORP
PANEL AXIAL COMPRESSION TEST SET UP

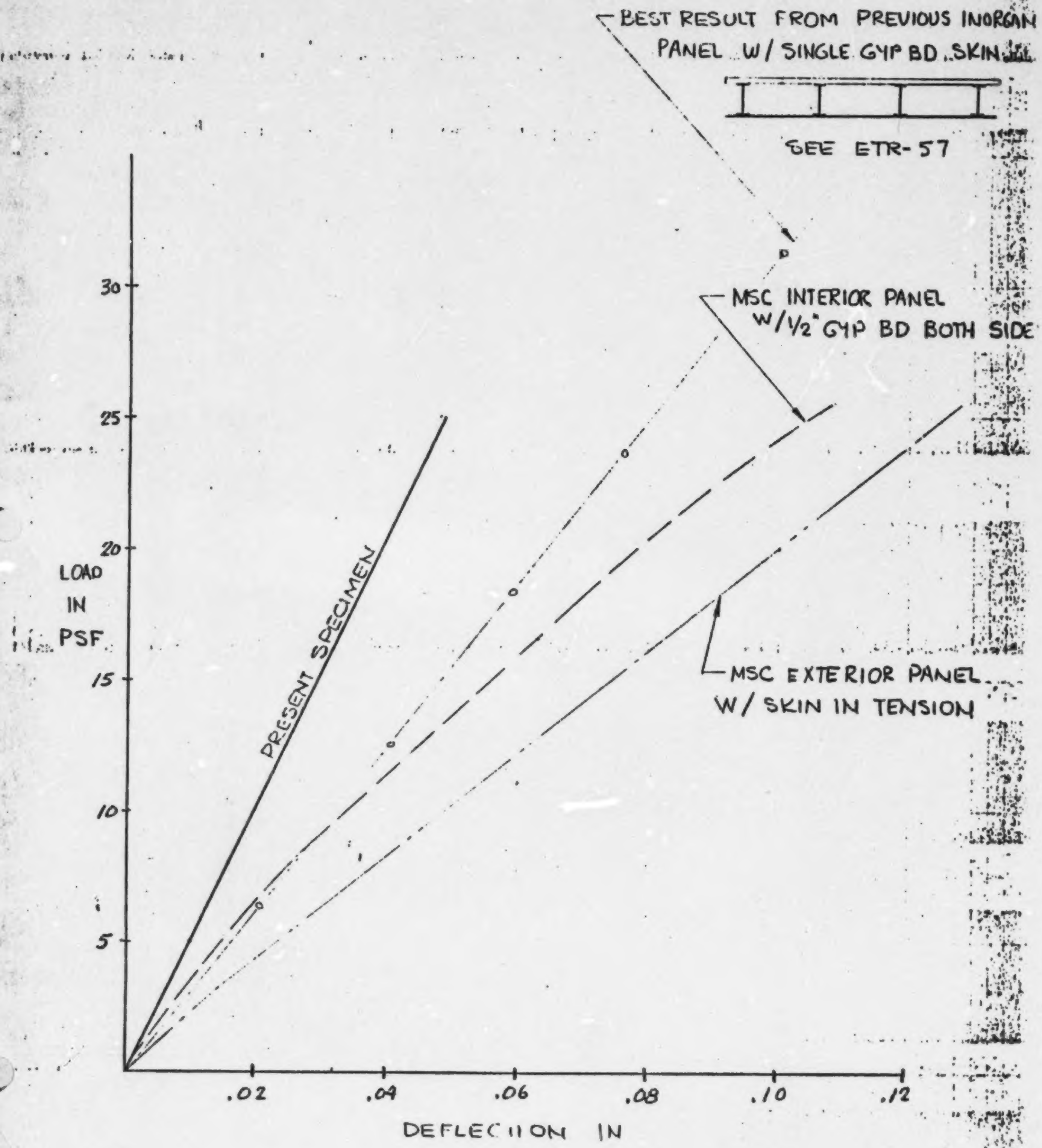


FIG 4
FLEXURE TESTING RESULTS

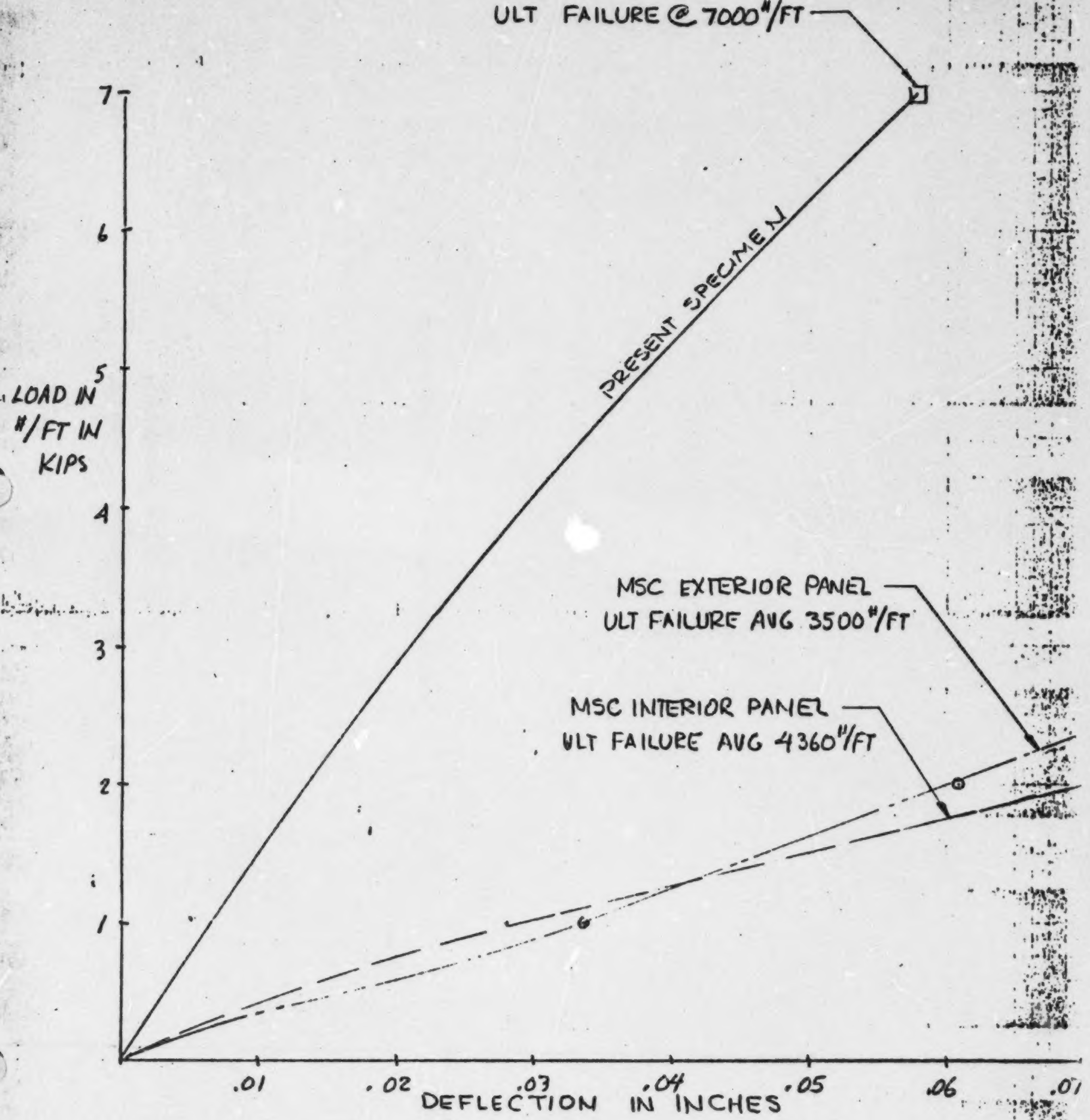


FIG 5
AXIAL COMPRESSION RESULTS

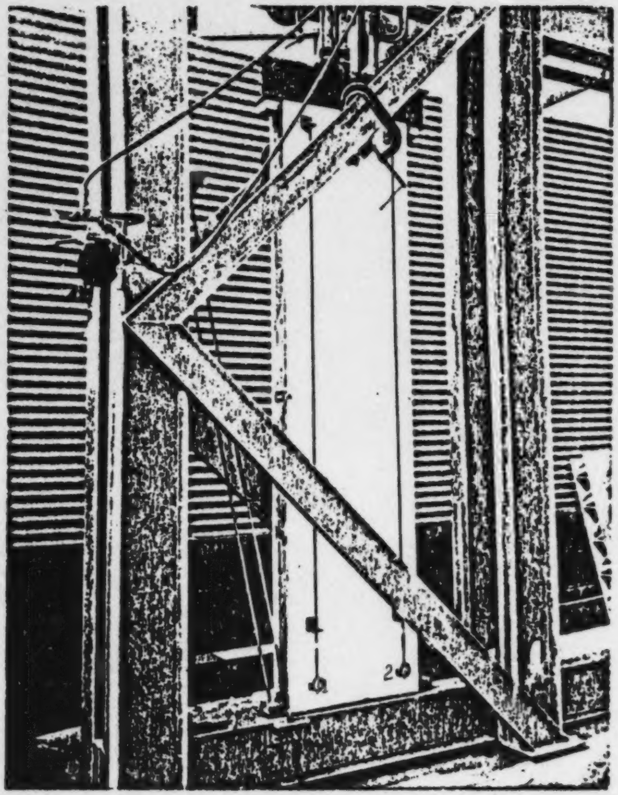


FIG 6

SPECIMEN IN AXIAL COMPRESSION
TEST APPARATUS

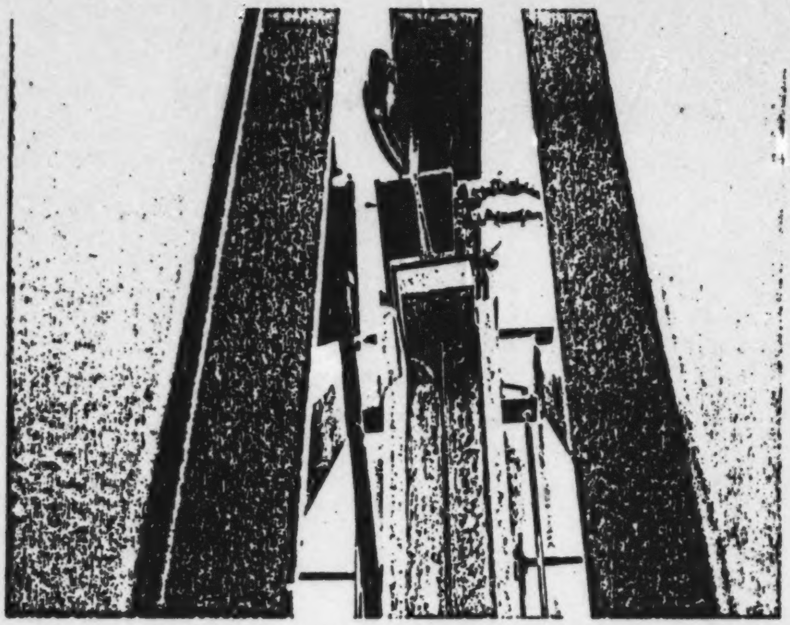


FIG 7
FAILED SPECIMEN

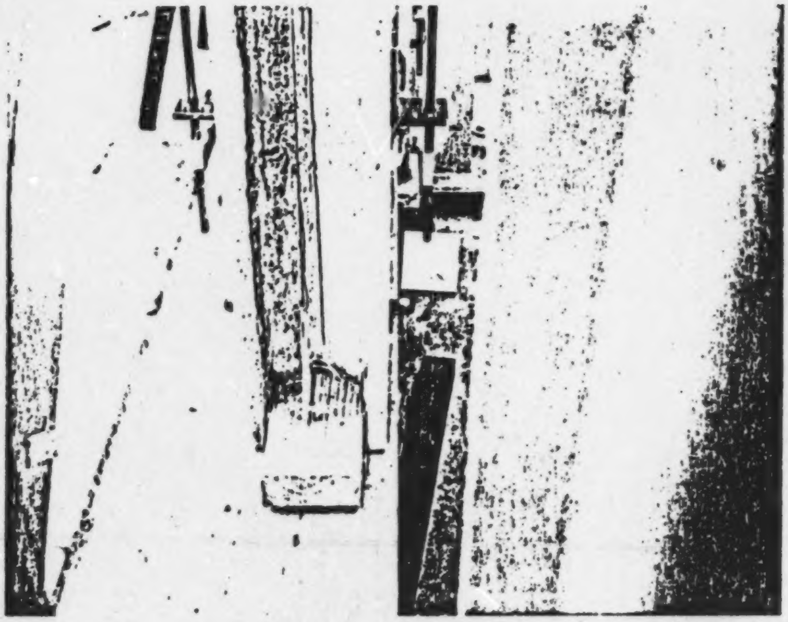
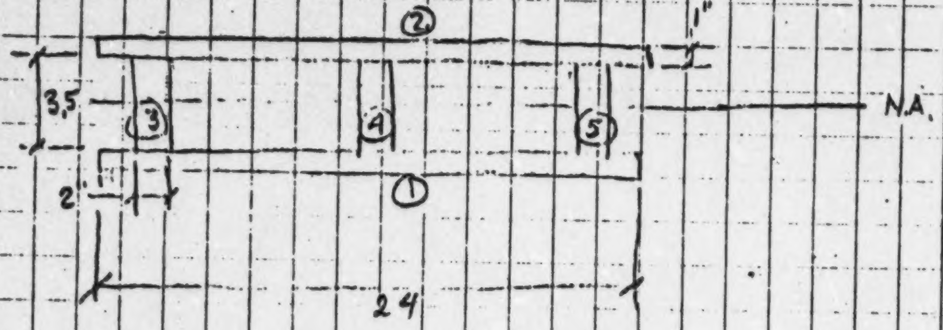


FIG 8
FAILED SPECIMEN

CALCULATIONS

1. MOMENT OF INERTIA



ITEM	A	Y	Ay	Ay^2	I_o
1	24	2.25	54	122	2
2	24	2.25	54	122	2
3	7	0	0	0	7
4	7	0	0	0	7
5	7	0	0	0	7
Σ				244	25

$I_{xx} = \Sigma Ay^2 + I_o$

$= 244 + 25 =$

$\underline{269 \text{ IN}^4}$

OR $\frac{269}{2} = 134 \text{ IN}^4/\text{FT}$

2. SECTION MODULUS

$\Delta = \frac{Pa}{24EI}(3l^2 - 4a^2)$, $EI = \frac{Pa}{24\Delta}(3l^2 - 4a^2)$

USE 160# LOA
& .039 DEFL

$= \frac{160(24)}{24(.039)}(3 \times 93^2 - 4 \times 24^2)$

$4100(25{,}900 - 2{,}300)$

$= \underline{95 \times 10^6} \text{ PSI}$

3. MODULUS OF ELASTICITY

$E = \frac{95 \times 10^6 \ \#/\text{IN}^2}{134 \text{ IN}^4} = .70 \times 10^6 \text{ PSI}$

APPENDIX G

MATERIAL SYSTEMS CORPORATION

TECHNICAL REPORT 75-002

DESIGN AND TEST CRITERIA FOR FLOOR AND FLOOR-CEILING ASSEMBLIES

Prepared for EPA Contract No. 68-03-2056

Prepared by BLW for
Jere Robinson

Prepared by BLW for
Stephen Feher

Approved by Bud L Duft
Bud L. Duft
President

INTRODUCTION

This report has been prepared to outline criteria for the design and test for floor and floor-ceiling assemblies utilizing new materials in sandwich panel type construction.

The requirements are limited to defining the performance criteria of a specific structural element and not the entire building.

The physical and mechanical characteristics of the new materials that may be developed for this application are unknown at this time. Therefore, the design requirements and test methods specified in this report are of a general nature which will have to be modified and expanded to accomodate the specific materials. The general design and test criteria in this report are based on the HUD Guide Citeria developed by the National Bureau of Standards for Operation Breakthrough. Some modifications, reflecting more stringent requirements have been made where applicable as specified by the following:

- FHA Minimum Property Standard (1973 Edition)
- Uniform Building Code (1973 Edition)
- The Requirements of the International Conference of Building Officials (ICBO) for qualification of new construction materials and methods.

FLOOR/CEILING

SUMMARY OF REQUIREMENTS

1. Structural Serviceability
   - 1.1 Vertical Deflection
   - 1.2 Vibration
   - 1.3 Occupancy Loads
2. Structural Safety
   - 2.1 Vertical Loads
   - 2.2 Horizontal Shear Loads
3. Fire Safety
   - 3.1 Fire Endurance
   - 3.2 Flame Spread
   - 3.3 Smoke Generation
   - 3.4 Potential Heat (Combustibility)
4. Acoustic Separation
   - 4.1 Sound Transmission Class Rating and Impact Insulation Class Rating

1. STRUCTURAL SERVICABILITY

1.1 Vertical Deflection

Requirement

Interior horizontal space dividers or floor-ceiling assemblies should not defect excessively under service load.

Criterion

With the full dead and live load in place the total deflection, which includes the deflection due to long-term sustained load, should not result in:

1.1.1 delamination, spalling or other local damage to any element.

1.1.2 damage to other built elements at their interface with the deflected structural element.

1.1.3 damage to mechanical and service subsystems.

1.1.4 damage to the structural element itself by high local curvature.

1.1.5 interference with the drainability of surfaces, or change in permeability or desired slope of surfaces.

1.1.6 interference with the functioning of doors and windows, or with other built elements or systems by exceeding dimensional tolerances provided for these elements or systems.

1.1.7 undesirable esthetic effects.

In addition, the following deflection limitations are to be met:

1.1.8 With the full dead load in place, the deflections due to the superimposed live load of $40\#/ft^2$ should not exceed the following:

Recommended Limit: $dv = \frac{"l"}{360}$ *

Extreme Limit: $dv = \frac{"l"}{240}$ *

* Including long term creep deformation

Test

Full scale test in accordance with ASTM E 72 "air bag method" and as specified in ICBO Research Committee Acceptance Criteria for Sandwich Panels.

Commentary

Criteria 1.1.1 through 1.1.7 defines limitations to deflections in terms of damage and inconvenience that may be caused. This is important for the reason that adherence to a specific numerical value is meaningless is the deflection is damaging. Considerations of structural behavior therefore override any specific stipulated limit. In Criterion 1.1.8, specific deflection limitations are defined. These limitation reasonably represent present professional consensus. In general, the recommended limit is consistent with currently accepted good design practice, FHA and UBC requirements. The extreme limit may be acceptable to FHA and UBC (ICBO) but would require justification based on meeting criteria 1.1.1 through 1.1.7.

1.2 Vibration

Requirement

Structural vibrations should not cause discomfort to occupants and should not impair structural serviceability.

Criterion

1.2.1 Transient Vibrations:

In any horizontal space divider supporting human activity, installed in the building with its surface covers and with all partitions and fixed furniture in place, transient vibrations induced by human activity should decay to 0.2 of their initial displacement-amplitude within a time not to exceed 1/2 second.

Test

Full scale panel test to measure vibration decay time.

1.3 Occupancy Loads

Requirement

Floor-Ceiling assemblies should not be damaged by occupancy loads.

Criterion

1.3.1 Floors in service should withstand an impact energy of 750 ft-lb at any location, with a residual net deflection not to exceed 10 percent of the maximum net deflection due to the impact load, or "1"/4000, whichever is greater, measured one hour after impact. An exception to this is the case where the floor consists of stiffening elements supporting a floor deck. In this case, the floor should resist the stipulated 750 ft-lb impact energy delivered to the floor deck coincident with the axis of the stiffening element, without exceeding the stipulated residual deflection and a 300 ft-lb impact energy delivered to the floor deck at the other location without failure of the floor.

1.3.2 The structural floor should resist a 400 lb. load, applied on a circular area of 5/8 in. diameter and sustained for one hour, without causing a residual indentation of the structural surface in excess of 1/16 in. measured one hour after removal of the load and a 280 lb. long-term sustained load applied over a circular area of 5/8 in. diameter.

If the wearing surface is of a nondurable material, or if there is a possibility that this surface may be removed during the useful life of the structure, the floor should satisfy the above criterion with the wearing surface removed.

1.3.3 Ceilings should not fail, delaminate (except for decorative surface membranes), crack, spall, or exhibit residual deflection in excess of 25 percent of vertical net deflection, or "1"/4000, whichever is greater, under the following loading:

Five times the dead load (5D) or 4 lb/ft^2, whichever is greater, applied vertically downward.

Test

For Criterion 1.3.1, physical simulation, using testing apparatus described in ASTM E 72, except that chilled lead shot (No. 7 1/2) should be used to fill the sand-bag to a gross weight of 150 lb.

For Criterion 1.3.2 ASTM E 72 test for concentrated load, except that the test may be performed on a small specimen (2 ft x 2 ft), and the load will be applied over a circular area of 5/8 in. diameter.

For Criterion 1.3.3, analysis and/or plysical simulation where feasible.

Commentary

Criterion 1.3.1 intends to determine whether the floor will withstand occasional impact loads resulting from occupancy (a man falling from a ladder) without suffering structural damage.

Criterion 1.3.2 deals with concentrated loads applied to the surface of the structural floor by certain tests of furniture and by other occupancy loads.

Criterion 1.3.3 requires that ceilings have a certain minimum strength to support their dead weight without sustaining structural damage due to long-term effects.

2. STRUCTURAL SAFETY

2.1 Vertical Loads

Requirement

The floor-ceiling panels should be capable of supporting long duration live loads with a sufficient margin of safety.

Criterion

The allowable vertical load is established as 1/3 of the average failure load of the panels determined in full scale test.

Test

Uniformally distributed load bending test in accordance with ASTM E 72 and ICBO Research Committee Acceptance Criteria for Sandwich Panels.

2.2 Horizontal Shear Loads

Requirement

The floor-ceiling panels and joints should have sufficient horizontal shear resistance to facilitate efficient structural design of two and three story buildings under high lateral wind and earthquake design conditions.

Criterion

The allowable horizontal shear load (diaphragms shears) of the floor panel system should be established as 1/5 of the average ultimate shear load of the panel joints as determined by testing.

Test

Special shear test should be designed to determine the ultimate shear load capacity of the joints between panels.

Commentary

In case of conventional plywood sheeted wood joist floor systems, the horizontal (diaphragm) shear resistance is determined by the nailing schedule. In case of a panelized floor system the limiting factor in shear resistance is the strength of the joints. The safety factor of 5 is conservative but necessary considering the nature of typical field bonded adhesive joints and the difficulty of predicting long term strength of the joints.

3. FIRE SAFETY

3.1 Fire Endurance

Requirement

The floor-ceiling assembly should contain the fire for a sufficient period to permit evacuation of occupants and to allow fire fighters to bring the fire under control.

Criterion

The fire endurance of the floor-ceiling system should equal or exceed the following:

*[1] Floor systems over a crawl space or basement - 10 min.

Other floor and floor-ceiling systems for single occupancy - 20 min.

Floor-Ceiling systems for multiple occupancy 1 Hr.

*[1] Note: For the case where the basement or crawl space contains furnaces, space heaters, or dryers, the ceiling immediately over the equipment should have a fire endurance of 20 minutes. This protection should extend for a minimum distance of 4 feet beyond the edge of the equipment.

Test

The fire endurance rating of a floor or floor-ceiling assembly should be determined by full scale fire test per ASTM E 119-67.

Commentary

Both the UBC and FHA Minimum Property Standards MPS specify a minimum of 1 hour for multiple family floor-ceiling separations. The MPS specifies a 20 minute rating for first floor assemblies for multiple family occupancies while the UBC specifies nothing. Similarly neither requires anything for single family occupancies but the Operation Breakthrough criteria asks for 10 minutes over a basement or crawl space and 20 minutes for all other assemblies. The above criteria have been set forth to reflect the most stringent of the combined requirements.

3.2 Flame Spread

Requirement

The floor or floor-ceiling surfaces should have flame spread characteristics related to the room use.

Criterion

The flame spread rating of the floor-ceiling surfaces should not exceed the following:

Ceiling Surface

Occupant Storage Room	75
Maintenance Storage Rooms	75
Maintenance Shops	75
Public Laundry Rooms	75

Rooms Containing Combustion Type Furnaces or Boilers	75 [*2]
Other Areas	200

Floor Covering

All Areas	200

Test

The flame spread test for all floor and floor-ceiling surfaces shall be determined in accordance with ASTM E 84 tunnel tests.

Commentary

The only existing firm criterion for maximum allowable flame spread for floor and ceiling surfaces is contained in the Operation Breakthrough requirements.

3.3 Smoke Generation

Requirement

Any smoke generated by the floor-ceiling surfaces in a fire should not exceed safe limits.

Criterion

The maximum specific optical density of the smoke generation by the floor-ceiling snadwich should not exceed the following:

Ceiling

Occupant Storage Rooms	150
Maintenance Storage Rooms	150
Maintenance Shops	150
Public Laundry Rooms	150

[*2] For open installations in a basement, this flame spread rating of the ceiling should extend 4 feet beyond the edge of the equipment.

Rooms Containing Combustion Type Furnaces or Boilers	150 *[3]
Other areas	300
Floors	
All Areas	450

Test

Smoke generation test for all floor and floor-ceiling surfaces shall be determined in accordance with ASTM E 84 tunnel test.

Commentary

The only existing firm criterion for maximum allowable smoke generation for floor and ceiling surfaces is contained in the Operation Breakthrough requirements.

3.4 Potential Heat-Combustability

Requirement

The amount of heat contributed to the fire by the materials used in the floor ceiling should be limited.

Criterion

The allowable potential heat (combustability) of the floor ceiling assembly is limited based on the type of building in which the assembly is used. They may be classed as combustable or non-combustable as follows:

CRITERIA FOR NON COMBUSTABLE CLASSIFICATION HUD/NBS CRITERIA.

3.4.1 The potential heat of the floor-ceiling assembly which applies only to the structural part of the assembly and its fire

*[3] For open installations in a basement, this smoke requirement of the ceiling should extend 4 feet beyond the edge of the equipment.

Criteria for Airborne and Impact Sound Insulation of Floor-Ceiling Assemblies between Dwelling Units

Partition Function between Dwellings			Grade II	
Apt. A		Apt. B	STC	IIC
Bedroom	above	Bedroom	52	52
Living room	above	Bedroom 1,2	54	57
Kitchen 3	above	Bedroom 1,2,4	55	62
Family room	above	Bedroom 1,2,5	56	62
Corridor	above	Bedroom 1,2	52	62
Bedroom	above	Living room 6	54	52
Living room	above	Living room	52	52
Kitchen	above	Living room 1,2,4	52	57
Family room	above	Living room 1,2,5	54	60
Corridor	above	Living room 1,2	52	57
Bedroom	above	Kitchen 1,4,6	55	50
Living room	above	Kitchen 1,4,6	52	52
Kitchen	above	Kitchen 4	50	52
Bathroom	above	Kitchen 1,2,4	52	52
Family room	above	Kitchen 1,2,4,5	52	58
Corridor	above	Kitchen 1,2,4	48	52
Bedroom	above	Family room 1,6	56	48
Living room	above	Family room 1,6	54	50
Kitchen	above	Family room 1,6	52	52
Bathroom	above	Bathroom 4	50	48
Corridor	above	Corridor 7	48	48

Notes Re: Table

1. The most desirable plan would have the floor-ceiling assembly separating spaces with equivalent functions, e.g., living room above living room, etc.: However, when this arrangement is not feasible the assembly should have greater acoustical insulating properties.
2. This arrangement requires greater impact sound insulation than the converse, where a sensitive area is above a less sensitive area.
3. Or dining, or family, or recreation room.
4. See HUD FT/TS-24 for proper vibration isolation of plumbing fixtures and appliances.
5. The airborne STC criteria in this table apply as well to vertical partitions between these two spaces.
6. This arrangement requires equivalent airborne sound insulation and

protection should not exceed 5000 BTU per any square foot of floor-ceiling assembly excluding floor covering.

UBC Criteria

3.4.2 Material of which no part will ignite and burn when subjected to fire. Any material conforming to UBC standard No. 4-1 shall be considered noncombustible within the meaning of this section.

3.4.3 Material having a structural base of non-combustible materials as defined in 3.4.2 above, with a surfacing material *[4] not over 1/8 inch thick which has a flame spread rating of 50 or less. No material shall be classed as non-combustible which is subject to increase in combustibility or flame spread rating *[5] beyond the limits herein established, through the effects of age, moisture, or other atmospheric conditions.

Test

Potential heat of a floor-ceiling assembly may be calculated if the properties and quantities of the constituent materials are known. Otherwise it should be determined by experimental

*[4] Non-combustible does not apply to surface finish materials. Material required to be non-combustible for reduced clearances to sources of high temperature shall refer to material conforming to 3.4.2.

*[5] Flame spread rating as used herein refers to rating obtained according to tests conducted as specified in UBC Standard No. 42-1. (Same as ASTM E 84 Tunnel Test.)

measurements in accordance with ASTM Proceedings 61 (1961), "Potential Heat - A Method for Measuring the Heat Release of Materials in Building Fires", by J.J. Loftus et al. For UBC criteria see test specified in 3.4.2 and 3.4.3.

Commentary

There are no Operation Breakthrough criteria for single family dwellings and those given are for HUD multifamily occupancies.

4. ACCOUSTIC SEPARATION

4.1 Sound Transmission Class Rating

Requirement

No accoustic requirement exists for single family detached or attached housing but provision should be made for acoustical privacy in multi-level detached and attached as well as in multi-family dwellings.

Criterion - Multi Level Single Family Detached and Attached

Sound transmission Class STC-50 and impact insulation Class IIC-50 to be determined by laboratory test of floor-ceiling assembly.

Criterion - Multi-Level Multi-Family Dwellings

Grade II criteria of table of "A Guide to Airborne Inpact and Structure Borne Noise Control in Multi-family Dwellings" HUD FT/TS-24.

APPENDIX H

CEILING PANELS

CEILING PANELS

The following documents provide a survey of available ceiling panels and ceiling system designs.

PRODUCT SUMMARY

DESCRIPTION	SMOKE	SIZE	FLAME SPREAD	COST/FT²	lbs
KEENE (609-452-8800) Princeton, New Jersey					
-Styletone - Mineral Fiber - Time Rated for floor/Ceiling (3 Styles)	Yes	3/4" 1'x1' 1'x2'	25	–	–
-Hansonite - " " Ceiling Only (4 Styles)	Yes	1/2"-5/8"x 1'x1'	25	–	–
-Hansoguard - " " Vinyl Finish Ceiling Only (2 Styles)	Yes	5/8"x 1'x1'	25	–	–
-Hansoboard: Same as Hansoguard except larger (5 Styles)	Yes	5/8 x2'x2'-6'	25	–	–
-ACF - Mineral Fiber - Ceiling Only (3 Styles)	Yes	5/8"-1"x2'x4'	25	–	–
GOLD BOND (213-435-4465) DIV. OF NATIONAL GYP. BUFFALO, NEW YORK					
-Fire-Shield Solitude - Time Rated for floor/ceiling (5 styles)					
Vinyl Acrylic Coating standard	No	1/2" 2'x2' 5/8"x 2'x4'	15	.35	–
Vinyl Acrylic Coating textured } Humidity sensitiv	No	"	20	.185	–
Acrylic Plastic	Yes	"	25	.155	–
MR - Moisture Resistant	Yes	"	25	.155	–
-Fire-Shield Travacoustic - Ceiling only Acrylic plastic - Humidity Sens	Yes	3/4"x 1'x1' 2'x2'	15	—	–
-Fire Shield Acoustimetal - Time rated (3 styles) Acoustic control.	Yes	3/4"x1'x1' x1'x2'	25	–	–
-Asbestibel - Asbestos fibers and cement binder (2 styles)	Yes	3/16"x 2'x2' 2'x5'	0	–	–
-Tectum - Wood fibers/MgOCl (1 style)	No	1"-3"x 2'x2' x2'x4'	20	.48 -.395	—
OWENS-CORNING (213-724-5383) TOLEDO, OHIO.					
-Acoustical Tiles - Ceiling and walls - Fiberglass (12 Styles)	No-Yes	5/8"x 1'x1' 2"x 2'x4'	15-25	.16	–
-Mondrian Panels - Ceiling	Yes	1"x2'x8' 1"x4'x8'	25	.390	–
SIMPSON, (213-627-3417) Simpson Timber 200 Washington Blvd Seattle,					
-Forestone - Cellulose ceiling only (4 styles)	Yes	1/2" 1'x1' 3/4"- 1'x2'	26-75	.280	.7-.9
-PyRotect - " " " (5 styles)	Yes	1/2"- x 1'x1' 3/4"- x 2'x4'	20	.280	.8-1.
-Firerate - Mineral Fiber - Time rated for floor & ceiling (7 Styles)	Yes	5/8-1" x 1'x1' 2'x5'	25	.310	.8-1.5
-Classe' - Mineral Fiber -	Yes	1/2" x1'x1' 3/4" x2'-4'	25	–	.7-1.4

TABLE-1 · CONT'D

PRODUCT SUMM[illegible]RY

DESCRIPTION	SMOKE	SIZE	FLAME SPREAD	COST/Ft²	LD/
U.S. GYPSUM (213-388-1171) 101 So Wacker Drive, Chicago, Illinois					
-Acoustone - Molded mineral fiber - Time rated floor/ceiling (12 Styles)	Yes	3/4" x1'x1' x2'x4'	15	.185	1.3-
-Auratone - Water felted mineral fiber - Time rated floor/ceiling (6 Styles)	Yes	5/8" x2'x2' x2'x5'	25	.170	1.15-
- Gypsum Ceiling - Gypsum and Vinyl (1 Style)	No	1/2" x2'x2' 5/8" x2'x4'	15	—	1.88-
- Hi lite - Water felted mineral fiber - Ceiling only (1 style)	Yes	5/8" x2'x2' x2'x4'	25	-	1.c
- Asbestos Board - (1 style)	Yes	3/16 2'x2' 2'x4'	0	.20-.30	1.5-
ACOUSTIFLEX (312-879-7313) Box 434 BATAVIA, ILLINOIS.					
-Vinyl Rock - Gypsum with Vinyl Film. (2 Styles)	Yes	1/2" 5/8" x2'x4'	0	—	—
-Vinyl Rock - Mineral Board (2 Styles)	Yes	5/8" x2'x4'	25	-	-
-Aluminum Clad on the above	0	Above	0	—	—
-Acousticore - Glass Fiber Board (3 Styles)	Yes	5/8" x2'x4' 1" x2'x5'	25	-	-

PRODUCT SUMMARY

DESCRIPTION	Smoke	Size	Flame Spread	Cost/ft²	Tbs
CELOTEX (213-223-0911) Home Office - Tampa, Florida					
-Basic Types; Safetone - Used for ceiling applicaton only	Yes	3/4" × 2'×2' 2'×4'	25	0.165	.75-
Protectone - Time rated for floor/ceiling comb.	Yes	3/4" × 2'×2' 2'×4'	25	0.195	.75-
Note: There are a variety of textures (7)					
ARMSTRONG (213-686-1940) District Office - L.A. 9700 Flair Dr El Monte					
- Fireguard (Cermaguard) - Time rated for floor/ceiling (25 styles)	Yes	3/4" × 2'×2' 2'×5'	25	—	—
- Travertone - Minatone - Classic } - Used for ceiling application only (34 Styles)	Yes	7/8" × 1'×1' 2'×4'	25	—	—
- Trilon - " " " " " (1 Style)	Yes	3/4" × 1'×1'	25	0.289	—
- Cushiontone - " " " " " (Wood Fiber) (3 Styles)	Yes	3/4" × 1'×1' 2'×4'	200	0.169	—
CONWED (213-685-7400) Home Office: 332 Minnesota St. St. Paul (ZANGLER)					
- Lay in Panels - Mat's range from mineral fibers to ceramic and can be used in floor/ceilings. (14 styles)	No - Yes	5/8" × 1'×1' 2'×4'	25-75	.15—.355	.9
- Specialty Panels - Used as ceilings only (3 Styles)	Yes	5/8" × 2'×2' 2'×4'	25	.188—	.9
Concealed Tiles - " " " " (12 styles)	Yes		25-75	.15—.188	.9
JOHNS-MANVILLE (213-564-6701) Home Office: Greenwood Plaza, Denver, Colo (Kenman)					
Acousti-Clad - Aluminum clad surface with perlite core or felted mineral core, or a special treated mineral core. (9 styles)	Yes	5/8" × 1'×1' 7/8" × 1'×1'	25	—	—
Sculptured Fiberglass Panels - Press molded panels (3 Styles)	Yes	5/8" × 2'×2' 4'×4'	25	—	—
Firedike - Felted mineral fibers. Time rated for floor/ceilings (12 Styles)	Yes	5/8" × 1'×1' 2'×2'			
Permacoustic - Cast mineral fiber. (2 Styles) Ceiling Only		3/4" 2'×4'	25	.275	—
Quadrette - Felted mineral fibers, Time rated (2 Styles)	Yes	3/4" × 2'×4' 2'×2'	25	.245-.275	—
Spintone - Felted mineral fibers, Ceiling Only (6 Styles)	Yes	5/8" 2'×2' 5/8" × 2'×5'	25	.155-.185	-
Tempetone - Felted mineral fibers, Ceiling Only (3 Styles)	Yes	5/8 × 1'×1'	25	—	—
Tenu-Tone - Felted mineral fibers, Ceiling Only (3 Styles)	Yes	5/8 × 1'×1'	25	—	—
Transite Panels - Mineral fibers, Calcium Alumina Silicate formed and cured under hydrothermal Conditions.	—	1 1/16" × 2'×2' 3/4" 2'×5'	25	9.00-8.00	

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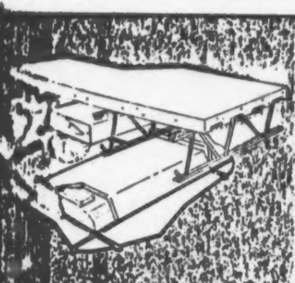
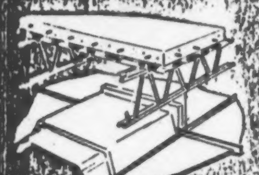
9.1/Co

FIRE-RATED CONSTRUCTION floor and ceiling test details

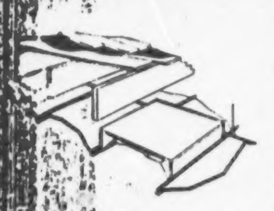
Conwed



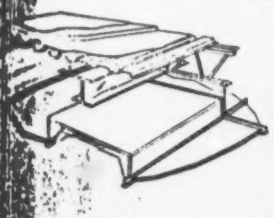
U.L. design 305 (G-203) — 2 hour — Floor section of this design consisted of 3" of concrete, steel bar joists spaced 30" o.c., fluted steel decking, and a 10" steel beam. Ceiling membrane consisted of Conwed nominal ⅝" x 24" x 48" FR2 Ceiling Panels, Conwed 1201 Series Suspension System, glass fiber air tube, and 24" x 48" light fixtures protected by Conwed FR Light Fixture Protection Batts.



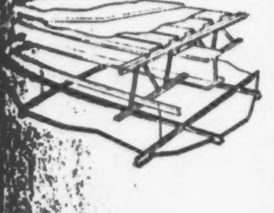
U.L. design 280 (G-204) — 2 hour — This design construction included ⅝" x 24" x 48" Conwed fire-rated Ceiling Panels, Conwed fire-rated Suspension System, 25% protected light fixtures, and air duct openings 113 square inches per 100 square feet of ceiling area.



U.L. design 45 (L-202) — 1 hour — This construction included ½" x 24" x 60" Conwed fire-rated Ceiling Panel. Conwed fire-rated grid with 5' long cross tees were used. Design 45 also included 16% of the ceiling with protected recessed light fixtures and a duct with two 12" diameter openings. Standard grade materials included, 2" x 10" wood joists and wood bridging.



U.L. design R/C 13 (P-202) — 1 hour — This new roof ceiling construction included ⅝" x 24" x 48" Conwed fire-rated Ceiling Panels. Conwed fire-rated Suspension System was used, and protected a 26 gauge fluted steel deck and built-up roof with 1" of insulation. The design included 16% protected light fixture openings with 57 sq. inch duct opening per 100 sq. ft.; the bar joists were 4' o.c.



U.L. design R/C 7 (P-201) — 1 hour — This Roof Ceiling construction included ⅝" x 24" x 48" Conwed fire-rated Ceiling Panel. Conwed fire-rated suspension system was used, and protected a 20 gauge fluted steel deck and built up roof with ¾" of insulation. There were no penetrations, and the bar joists were 7' o.c.

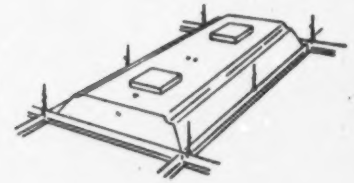
FIXTURE PROTECTION BATTS

2' x 4' and 1' x 4' Non-Air Troffer Configuration

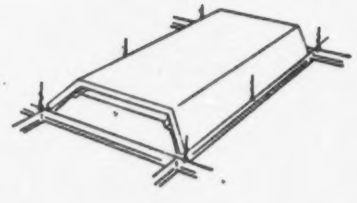
The use of Conwed FR Light Fixture Protection Batts can greatly reduce the labor required to protect recessed fixtures, thus reducing the cost of installing and bidding projects specifying fire-rated time design ceilings.

Procedure

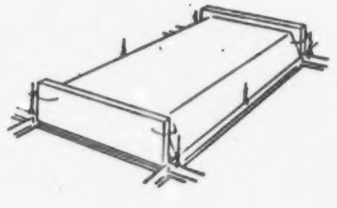
1. Tear 6" x 6" spacers from end pieces by hand, and place on fixture 6" in from each end.



2. Wedge 30" x 4' top piece between fixture body and hanger wires; form over spacers and wedge down between wires and fixture on opposite side.



3. Stand 6" x 24" end pieces loosely at each end. Hold in place with a light gauge twisted wire at each corner.

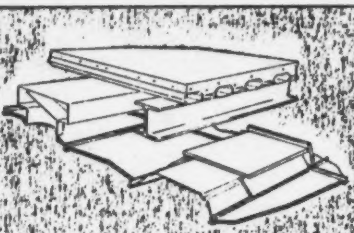


Conwed FR Light Fixture Protection Batts are approved for use in these Conwed designs:

224 (A-204)	3 hour
43 (A-815)	2 hour
233 (G-240)	2 hour
280 (G-204)	2 hour
282 (G-202)	2 hour
288 (G-006)	2 hour
305 (G-203)	2 hour
307 (J-201)	2 hour
309 (G-215)	2 hour
318 (G-007)	2 hour
45 (L-202)	1 hour
48 (G-206)	1 hour
RC-13 (P-202)	1 hour
RC- 1 (P-203)	45 min.

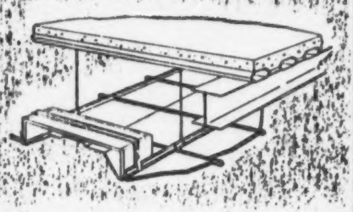
Conwed Corporation has conducted a great variety of full scale fire tests at Underwriters' Laboratories' Northbrook testing facilities in accordance with ASTM E-119, the standard fire test for resistance to the penetration of fire through a floor/ceiling or roof/ceiling construction. The details of some of these useful tests are shown below, for your interpolation and use in specifying Conwed fire-rated (UL labeled) materials. The tests are grouped by hourly time design category.

U.L. design 224 (A-204) — 3 hour (Beam 4 hours) — This design included ⅝" x 24" x 48" fire-rated Ceiling Panels, with 3" of concrete over cellular steel deck supported by a 10" steel beam. The ceiling had 24% light fixture openings and air duct opening of 113 square inches per 100 square feet of ceiling area.

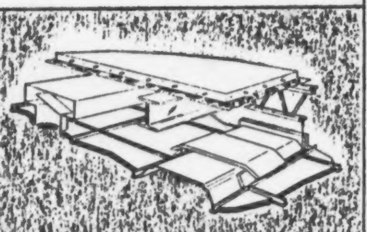


U.L. design 45 (A-003) — 3 hour (Beam 3 hours) — This construction included ¾" Conwed fire-rated Ventilating Tile in a Conwed concealed Z suspension system and recessed lighting fixtures.

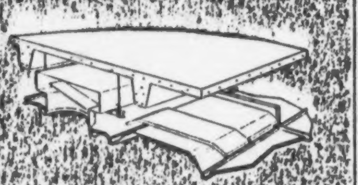
The Z runners, installed on 12" centers, are attached to carrying channels at approximately 4' intervals.



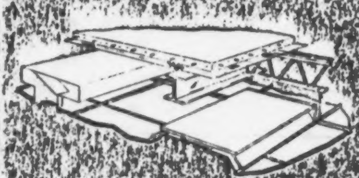
U.L. design 309 (G-215) — 2 hour — Floor section of this design consisted of 2½" of concrete over bar-joists and steel beam. Ceiling membrane consisted of ¾" x 24" x 24" fire-rated Reveal Edge Ceiling Panels, 25% light fixture openings protected by Conwed Light Fixture Protection Batts.



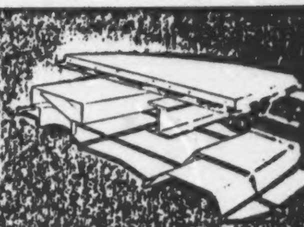
U.L. design 307 (J-201) — 2 hour — Floor section of this design consisted of reinforced concrete pan-joists. Ceiling membrane consisted of Conwed ⅝" x 24" x 48" fire-rated Ceiling Panels, Conwed fire-rated Suspension System, 25% light fixture openings protected by Conwed Light Fixture Protection Batts, and a duct with two 14" diameter openings.



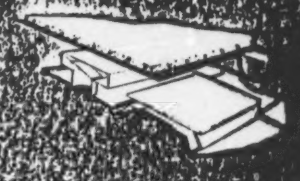
U.L. design 288 (G-006) — 2 hour — Floor section of this design consisted of a 2½" concrete, steel bar joists spaced 24" o.c. and steel beam. Ceiling membrane consisted of Conwed ¾" x 24" x 24" fire-rated butt kerfed and rabbeted ceiling tile supported by the Conwed fire-rated 440 concealed accessible suspension system. Protected light fixtures not to exceed 25% of ceiling area. Duct opening not to exceed 110 square inches per 100 square feet of ceiling area.



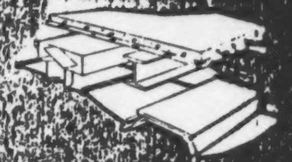
U.L. design 318 (G-007) — 2 hour (Beam 2 hours) — This design included 2½" of concrete over bar joists and 10" steel beam. The ceiling consisted of ⅝" x 12" x 12" to ¾" x 24" x 24" ceiling tiles with 25% recessed light fixtures and 196 square inches per 100 square feet duct openings.



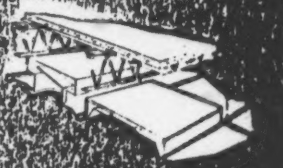
U.L. design 282 (G-202) — 2 hour — This construction included ⅝" x 24" x 24" Conwed Ceramic Ceiling panels. Conwed fire-rated suspension system was used. This design also included 25% protected light fixture openings and two 12" diameter duct openings.



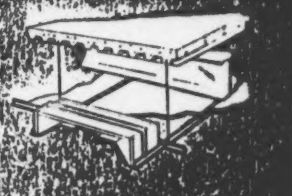
U.L. design 306 (G-213) — 2 hour (Beam 3 hours) — This design included ⅝" x 24" x 48" fire-rated ceiling panels with 2½" of concrete, 10" steel beam, Conwed fire-rated suspension system, 25% protected light fixture openings, and air duct with 576 square inch opening per 100 square feet of ceiling area.



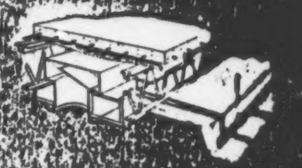
U.L. design 233 (G-240) — 2 hour — This construction included ⅝" x 24" x 48" Conwed fire-rated Ceiling Panel. Conwed fire-rated suspension system with 5' long cross tees were used. Design 233 also included 25% of the ceiling with protected recessed light fixtures and a duct with two 12" diameter openings.



U.L. design 43 (A-815) — 2 hour (Beam 4 hours) — This construction included Conwed fire-rated Ceiling Panel in a Conwed fire-rated suspension system. This economical alternating fluted and one-half cell steel deck also included recessed lighting fixtures.



U.L. design 258 (G-002) — 2 hour — This construction included Conwed standard fire-rated and ventilating fire-rated tile in a Conwed concealed Z suspension system clipped and suspended from a bar joist concrete assembly. This design also included 25% of the ceiling area with recessed light fixtures and ducts.



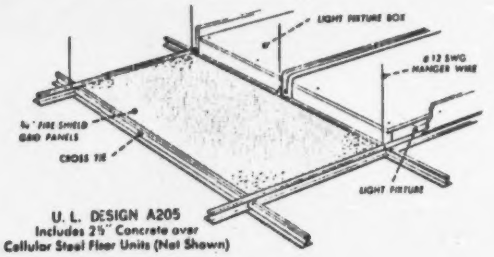
TIME-TEMPERATURE/DESIGN DATA

Source: Underwriters' Laboratories Fire Resistance Index and Factory Mutual Research Corporation

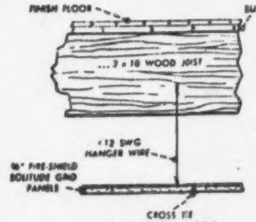
Design No.	New U. L. Design No.	Sizes	Lights/100' Sq. Ft.	Air/100' Sq. Ft.	Floor or Roof/Ceiling Construction
UL39 — 1HR	L204	2' x 4'	16 sq. ft.	57 sq. in.	Wood Joist and Floor
UL58 — 2HR	G219	2' x 2'/2' x 4'	24 sq. ft.††	576 sq. in.†	Bar Joist — ⅜" Ribbed lath* — 2½" Conc.
UL64 — 2HR	G220	2' x 2'/2' x 4'	20 sq. ft.†††	28 sq. in.	Bar Joist — ⅜" Ribbed Lath — 2½" Conc.
UL78 — 2HR	G221	**2' x 4'	8 sq. ft.	57 sq. in.	Bar Joist — ⅜" Ribbed lath* — 2½" Conc.
UL73 — 2HR (Beam — 2HR)	A206	**2' x 2'/2' x 4'	8 sq. ft.	576 sq. in.	Steel beam — cellular steel — 2½" Conc.
UL74 — 3HR (Beam — 4HR)	A205	***2' x 4'	16 sq. ft.	55 sq. in.	Steel beam — cellular steel — 2½" Conc.
UL31 — 1½HR	G224	2' x 4'	24 sq. ft.	113 sq. in.	Bar Joist — ⅜" Ribbed Lath — 2½" Conc.
UL279 — 2HR	G223	1½' or 2' x 5'	24 sq. ft.	576 sq. in.	Bar Joist — ⅜" Ribbed lath* — 2½" Conc.
FC37 — 1HR		2' x 2'/2' x 4'	16 sq. ft	55 sq. in.	Bar Joist — Insulated Fluted Steel Deck
RC84 — 1HR		2' x 4'	25 sq. ft.	55 sq. in.	Bar Joist — 2" Tectum Roof Plank
FC112 — 2HR		2' x 4'	20 sq. ft.	110 sq. in.	Bar Joist — Corrugated Steel — 2½" Conc.
RC133 — 2HR		***2' x 4'	16 sq. ft.	110 sq. in.	Bar Joist — Corr. Steel — 2" Perlite Conc.
FC152 — 2HR (Beam — 3HR)		2½' x 5'	25 sq. ft.	110 sq. in.	Bar Joist — ⅜" Ribbed lath — 2½" Conc.

*Alternate form: 28 ga. Corrugated Steel
**Approved for through (vent) perforations
***Panel Thickness ¾" — all others ⅝"

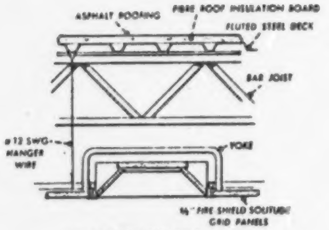
† 2' x 4' size only, otherwise 28 sq. in.
†† 12 sq. ft. with fire rated fixture
††† 8 sq. ft. with fire rated fixture


LIGHT FIXTURE BOX
#12 SWG HANGER WIRE
¾" FIRE SHIELD GRID PANELS
CROSS TIE
LIGHT FIXTURE

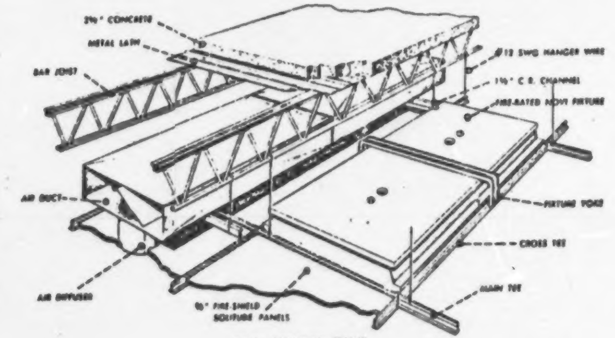
U. L. DESIGN A205
Includes 2½" Concrete over
Cellular Steel Floor Units (Not Shown)


FINISH FLOOR
SUB-FLOOR
2 x 10 WOOD JOIST
#12 SWG HANGER WIRE
⅝" FIRE-SHIELD SOLITUDE GRID PANELS
CROSS TIE

U. L. DESIGN L204
Ceiling also includes light Fixture
and Air Duct Outlets (Not Shown)


ASPHALT ROOFING
FIBRE ROOF INSULATION BOARD
FLUTED STEEL DECK
BAR JOIST
#12 SWG HANGER WIRE
YOKE
⅝" FIRE SHIELD SOLITUDE GRID PANELS

F.M. DESIGN NO. 37-1 HR.
Ceiling also includes Air Duct
Outlets (Not Shown)


2½" CONCRETE
METAL LATH
BAR JOIST
#12 SWG HANGER WIRE
1½" C.R. CHANNEL
FIRE-RATED VENT FIXTURE
AIR DUCT
FIXTURE YOKE
CROSS TEE
MAIN TEE
AIR DIFFUSER
⅝" FIRE-SHIELD SOLITUDE PANELS

U.L. DESIGN G219

architectural specifications

1. SCOPE

A. Gold Bond acoustical systems shall be installed only by an acoustical contractor approved by Gold Bond Building Products.

B. The acoustical contractor shall furnish all labor, materials, and equipment necessary for the complete acoustical installation as shown on the drawings and as specified.

2. GENERAL CONDITIONS

Acoustical materials shall be installed in accordance with procedures endorsed by the Acoustical and Insulating Materials Association. See "Job Conditions", p. 4.

A. All acoustical tile and panels shall conform to Federal Specification SS-S-118a and shall be as described in the current edition of the Acoustical and Insulating Materials Association Bulletin "Performance Data". Materials shall be delivered to the job in the manufacturer's original packages with seals unbroken, and with manufacturer's name and contents legibly marked thereon, and shall be stored and kept dry until used.

B. Panel units shall be Gold Bond Fire-Shield Solitude (state size). Surface shall be (select pattern and finish).

C. Suspension system shall conform to ASTM Standard C635 and installation shall be in accordance with ASTM Recommended Practice C636.

4. INSTALLATION

Acoustical units and suspension system shall be installed in pattern shown on the drawings and in strict accordance with the Underwriters' Laboratories or Factory Mutual construction design to obtain the specified time-temperature design rating of (   ) hour. Grid system shall be true, straight and level with border units of the greatest possible size.

5. VENTILATING CEILING SYSTEM

It shall be the responsibility of the acoustical contractor to provide and install zoning plenum barriers as required and to seal the plenum to prevent all leakage of conditioned air to ensure that air moves only through the ventilating acoustical units and into the occupied area.

REFERENCES

1. MSC Tech. Report 74-12.
2. "Fillers from Peanut Hulls - Better Than Wood" - G.R. Leghtsey, A.L. Hener, V.K.K. Sinha, Plastics Engineering, May 1975.
3. "Ash Utilization - Views on a Growth Industry" - J.N. Covey, J.H. Faber, Proceedings of the Third Mineral Waste Utilization Symposium.
4. Organic Syntheses - R. Adams, V. Voorkeer, Coll. Vol. 1 1941 page 281.
5. Economics - Peter Vajda, First Washington State University Symposium Particle Board, 1967.